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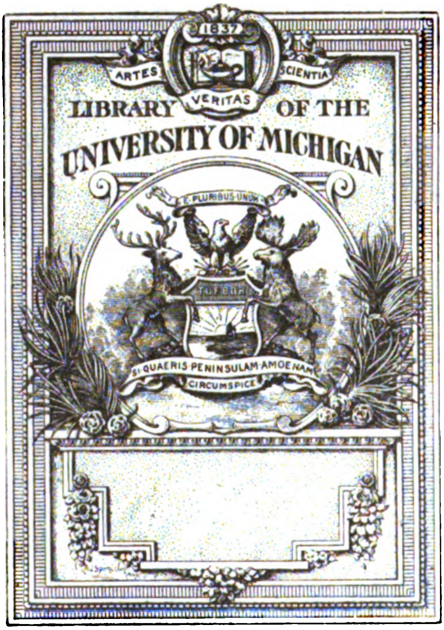
Bulletin

United States. Bureau of Animal Industry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Issued January 8, 1908.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 101.

A. D. MELVIN, CHIEF OF BUREAU.

THE AVAILABLE ENERGY OF RED CLOVER HAY.

INVESTIGATIONS WITH THE RESPIRATION CALORIMETER

IN COOPERATION WITH

THE PENNSYLVANIA STATE COLLEGE AGRICULTURAL
EXPERIMENT STATION.

BY

HENRY PRENTISS ARMSBY AND J. AUGUST FRIES.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., August 30, 1907.

Sir: I have the honor to transmit herewith and to recommend for publication as Bulletin 101 of this Bureau a manuscript entitled "The Available Energy of Red Clover Hay," by Dr. H. P. Armsby, and J. August Fries. This paper reports further experiments conducted with the respiration calorimeter by the Pennsylvania Agricultural Experiment Station in cooperation with this Bureau. Similar experiments in connection with timothy hay, red clover hay, and maize meal have previously been reported in Bulletins 51 and 74 of this Bureau.

Respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

State College, Pa., *July 1, 1907.*

Sir: I have the honor to submit herewith a report upon the third series of cooperative experiments with the respiration calorimeter at the Pennsylvania State College.

As in previous experiments, the details of the work have been in charge of Mr. J. August Fries, assistant in animal nutrition. Mr. Fries has been assisted by Messrs. W. W. Braman, A. K. Risser, T. M. Carpenter, R. E. Stallings, J. B. Robb, and John Foster, while the necessary chemical work was carried out by the chemical division of the experiment station under the general direction of Dr. William Frear.

Very respectfully, Henry Prentiss Armsby,
Expert in Animal Nutrition.

Dr. A. D. Melvin,
Chief of the Bureau of Animal Industry.

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THE AVAILABLE ENERGY OF RED CLOVER HAY.

INTRODUCTION.

The experiments reported in Bulletin 74 of this Bureau upon "Energy values of red clover hay and maize meal" gave somewhat questionable results for the net available energy of red clover hay. From a comparison of the first and second periods of that experiment an availability of 36.42 per cent was computed, but it was pointed out in reporting this result that the figures were comparatively low and must be accepted with considerable reserve. The experiment here reported, which was carried out during the winter of 1903–4, is a repetition of that portion of the previous experiment relating to clover hay, but upon a more extended scale, and shows that the doubt expressed as to the accuracy of the earlier figure for availability was apparently fully justified.

The general plan of the experiment was to feed the animal three different amounts of red clover hay, all less than the maintenance requirement, and to investigate the metabolism of the animal upon each ration at two different temperatures. Unfortunately, as appears in the following pages, the range of temperature within which the respiration calorimeter could be used was so limited that the experiments failed to afford any decisive results regarding the influence of temperature upon metabolism.

The animal used was the same grade Shorthorn steer which served in the experiments of 1901–2 and 1902–3. At the time of these experiments he was approximately 5 years old.

DESCRIPTION OF EXPERIMENTS.

ANALYTICAL METHODS.

The methods employed for the analysis of the feed and the excreta were substantially those recommended by the Association of Official Agricultural Chemists. The nitrogen of the feces was determined in the fresh material by König's method and the nitrogen of the urine by direct oxidation by the Kjeldahl method. In the computation of proteids from proteid nitrogen the conventional factor 6.25 was used both for the clover hay and for the feces. The nonproteids were computed from the nonproteid nitrogen by multiplication by

4.7, the factor for asparagin. Carbon and hydrogen were determined by combustion with cupric oxide in a current of air followed by oxygen. The heats of combustion of the feed and excreta were determined by means of the Atwater-Hempel bomb calorimeter.

THE FEEDS.

The hay used was red clover hay grown on the college farm in the summer of 1903. It was secured without rain and retained most of the leaves on the stems. On November 30 about a ton of this hay was run through a feed cutter and cut to lengths of about 7 to 10 centimeters. From the mass of cut hay two separate samples were taken by the same method as in previous experiments.[a] During the progress of the experiments a sample of hay was also taken at the time of weighing out for each period, as described in subsequent pages, or three samples in all. The following table shows the composition of the dry matter of the several samples, the generally close agreement of the results indicating that the method of sampling was sufficiently accurate:

TABLE 1.—*Composition of clover hay (dry matter).*

Constituents and energy.	General samples.			Samples taken during experiments.		
	A.	B.	Average.	Period I.	Period II.	Period III
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Ash	6.57			6.92	7.11	6.84
Proteids	11.69	10.66	11.18	12.11	11.82	11.84
Nonproteids	0.78	0.99	0.89	1.35	1.63	1.45
Crude fiber	28.78			28.45	28.02	28.83
Nitrogen-free extract	49.25			47.83	47.98	47.69
Ether extract	2.93			3.33	3.44	3.35
	100.00			100.00	100.00	100.00
Total carbon	46.43	46.04	46.24	46.57	46.24	46.17
Total nitrogen	2.039	2.042	2.041	2.223	2.238	2.205
Proteid nitrogen	1.872	1.818	1.845	1.935	1.890	1.895
	Calories.	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*
Heat of combustion, per gram	4.4932	4.4906	4.4919	4.4903	4.4888	4.478

PERIODS AND RATIONS.

On November 4, 1903, the steer was placed in a stall in the station barn and fed 6.35 kilograms of mixed clover and timothy hay with a little grain until December 2, 1903, when the grain ration was withdrawn. On December 26 the feeding of the ration used for the first period of the experiment was begun, and on January 2 the animal was transferred to a stall in the calorimeter building. The hay was given in equal amounts at about 6 p. m. and 6 a. m. Each period covered twenty-one days, of which the first eleven were regarded as a preliminary period and the last ten as constituting the digestion period proper. In view of the fact that all the rations were less than the maintenance requirement, intervals of seven days were interposed between the successive periods, during which the animal was removed to the station barn and fed a ration of 14 pounds of hay and 10 pounds of grain daily. The table shows the exact dates of the several periods and the rations fed.

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[a] Bulletin 51, Bureau of Animal Industry, p. 10.

TABLE 2.—*Dates and rations.*

Period.	Interval.	Preliminary period.	Digestion period.	Hay fed per diem.
				Kilograms.
I	December 26 to January 1	January 2 to 12	January 13 to 22	3.4
II	January 23 to January 29	January 30 to February 9	February 10 to 19	5.9
III	February 20 to February 26	February 27 to March 8	March 9 to 18	4.8

The animal was watered daily at about 1 p. m., with the exception of the days when he was in the calorimeter and the day before and after, when water was given immediately before the morning feeding.

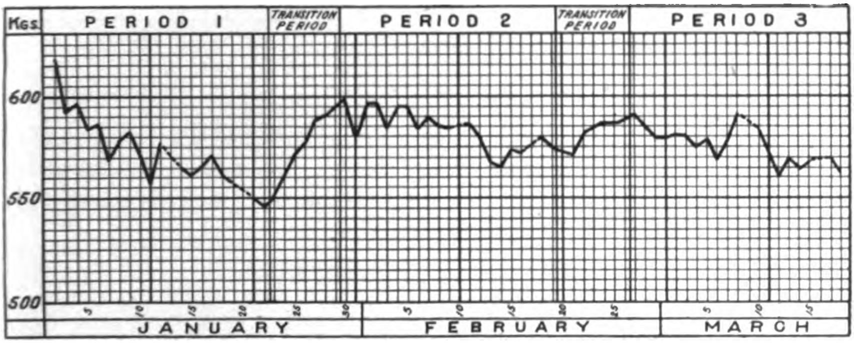

DIAGRAM 1.—Live weights of animal.

LIVE WEIGHTS.

The animal was weighed daily at 1 p. m., immediately before watering and also immediately after, the difference being taken as representing the amount of water consumed. On the days when the animal was in the calorimeter the weight was taken immediately before entering and immediately after leaving the apparatus. The figures for live weight and amount of water consumed are given in Table I of the Appendix in connection with the weights of the excreta, and the live weights are shown graphically on Diagram 1.

DETERMINATIONS OF DIGESTIBILITY.

WEIGHING AND SAMPLING OF FEED.

The hay for each period was weighed out in advance in cloth bags, a day's ration in a bag. In filling the bags the mass of hay was worked into from the side, taking all the material down to the floor. While the bags were being filled, two or three portions of the hay were taken from each bag and set aside in a covered vessel. Immediately after the weighing this was rapidly chopped in a meat chopper, thoroughly mixed, and a sample of 1,000 to 1,500 grams was taken to the laboratory in a covered vessel for determination of dry matter and of the composition of the latter, with the results shown in Table 1.

TREATMENT OF SAMPLES.

The samples when received at the laboratory were immediately weighed, air-dried at a temperature of about 60° C., allowed to hang at ordinary temperature in heavy paper bags for several days, and then ground in a mill as rapidly as practicable, and preserved in sealed bottles. The analyses were made as promptly as practicable, although not in all cases immediately.

HOURS OF FEEDING.

As a matter of convenience in arranging for the work with the respiration calorimeter, the hour of 6 p. m. was taken as the beginning of the day. Approximately one-half of the hay was given at this time and the remainder twelve hours later.

COLLECTION AND SAMPLING OF EXCRETA.

The animal was provided with the rubber duct described and illustrated in a previous publication[a] for the collection of the feces and with the ordinary urine funnel. These were worn both during the preliminary days and during the digestion period proper, but not during the intervals between the periods. The apparatus served its purpose excellently, loss of excreta occurring in but few instances.

During the digestion period the excreta were weighed promptly at the end of each twenty-four hours, and a sample was drawn after thorough mixing and taken at once to the laboratory for treatment. There a uniform percentage of the total excretion was set aside for a composite sample, chloroform being used as a preservative. At the close of the period these composite samples were thoroughly mixed. In the feces the total nitrogen in the fresh substance was determined by the König method, while a portion of the composite sample was also air-dried at about 60° C. and the air-dry sample subjected to the usual method of analysis, including the determination of its heat of combustion and of carbon and hydrogen. In the mixed sample of urine the total nitrogen, total carbon, hydrogen in organic combination, and heat of combustion were determined.

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[a] Pennsylvania Experiment Station Bulletin 42, p. 74.

DIGESTIBILITY OF RATIONS.

Period I (January 13-22, 1904).

The live weights of the animal and the weights of excreta are shown in Table I of the Appendix. The following table shows for the digestion period proper, the weight of hay fed, of hay eaten, and of the portions remaining uneaten; the weight of excreta collected, of the portions spilled, and of the total excretion; and the corresponding weights and percentages of dry matter found.

TABLE 3.—*Feed and excreta—Period I.*

Feed and excreta.	Fresh weight.	Dry matter.	
	Grams.	*Per cent.*	*Grams.*
Hay:			
Total in 10 days	34,000.0	86.32	29,348.8
Uneaten January 21[a]	63.0	3.33	2.1
Uneaten January 22	15.9	83.65	13.3
Total uneaten	78.9	....	15.4
Eaten	33,921.1	....	29,333.4
Eaten per day	3,392.1	....	2,933.3
Feces:			
Collected in 10 days	54,937.0	....	11,256.6
Spilled in calorimeter January 14	109.1	29.36	34.0
Adhering to duct January 14	18.0	....	6.1
Spilled in stall January 16	1.2	....	1.1
Spilled in calorimeter January 22	25.1	41.52	10.4
Spilled in stall January 22	36.6	28.44	10.4
Total excretion	55,127.0	....	11,318.6
Daily excretion	5,512.7	....	1,131.8

[a] Including water spilled in feed box.

The composition of the dry matter of the feeding stuffs has already been stated in Table 1, and that of the dry matter of the feces is shown in Table II of the Appendix.

Basing the computation upon the above average weights, the digestibility of the hay, as shown in Table III of the Appendix, was as follows:

TABLE 4.—*Digestibility of ration—Period I.*

Constituents and energy.	Total digested.	Digestibility.
	Grams.	*Per cent.*
Dry matter	1,801.4	61.41
Ash	89.4	44.04
Organic matter	1,712.0	62.70
Proteids	193.8	54.56
Nonproteids[a]	39.6	100.00
Crude fiber	462.2	55.37
Nitrogen-free extract	954.8	68.05
Ether extract	60.8	62.24
Nitrogen	39.36	60.36
Carbon	819.07	59.96
	Calories	
Energy	7,767.3[b]	58.97

[a] Assumed to be wholly digestible.

[b] The calorie referred to in this bulletin is the large calorie (kilogram-calorie; often written with a capital C). A calorie is the amount of heat required to raise the temperature of 1 kilogram (2.2 pounds) of water 1 degree centigrade, or about 4 pounds of water 1 degree Fahrenheit.

Period II (February 10–19, 1904).

The following tables, corresponding to those for Period I, summarize the weights of food and excreta and the percentage digestibility of the hay, which are contained in detail in Tables II and III of the Appendix.

TABLE 5.—*Feed and excreta—Period II.*

Feed and excreta.	Fresh weight.	Dry matter.	
	Grams.	*Per cent.*	*Grams.*
Hay:			
Total in 10 days	59,000.0	85.24	50,291.5
Uneaten February 17 [a]	580.0	2.15	12.5
Uneaten February 18	27.0	23.33	6.3
Uneaten February 19	23.2	88.11	19.5
Eaten	58,369.8	....	50,253.3
Eaten per day	5,836.9	....	5,025.33
Feces:			
Total in 10 days	97,807.0	19.75	19,316.88
Spilled in calorimeter February 12	142.4	24.09	34.3
Spilled in stall February 13	51.6	38.57	19.9
Collected in calorimeter February 19	56.2	49.34	28.46
Spilled in stall February 19	4.7	27.66	1.3
Total excretion	98,061.9	....	19,400.84
Daily excretion	9,806.19	....	1,940.1

[a] Including water spilled in feed box.

TABLE 6.—*Digestibility of ration—Period II.*

Constituents and energy.	Total digested.	Digestibility.
	Grams.	*Per cent.*
Dry matter	3,085.2	61.39
Ash	146.2	40.92
Organic matter	2,939.0	62.96
Proteids	321.2	54.08
Nonproteids [a]	81.9	100.00
Crude fiber	788.2	55.97
Nitrogen-free extract	1,636.9	67.90
Ether extract	110.8	64.08
Total nitrogen	69.02	61.37
Total carbon	1.391.9	59.89
	Calories.	
Energy	13,425.7	59.51

[a] Assumed to be entirely digestible.

Period III (February 27 to March 18).

In this period the final results were as follows:

TABLE 7.—*Feed and excreta—Period III.*

Feed and excreta.	Fresh weight.	Dry matter.	
	Grams.	*Per cent.*	*Grams.*
Hay:			
Total in 10 days	48,000.0	86.48	41,510.4
Residue March 9	28.0	88.57	24.8
Residue March 9	138.5	28.51	39.6
Residue March 10	5.8	87.93	5.1
Residue March 16			8.1
Residue March 17	29.4	91.83	27.0
Residue March 17			4.2
Residue at end of period			10.2
Eaten	47,746.1		41,391.4
Eaten per day	4,774.6		4,139.14
Feces:			
Total	75,693.0	21.38	16,183.16
Spilled March 11	37.0	61.62	22.80
Spilled March 18	20.6	61.16	12.60
Adhering to duct			53.00
Total excretion	75,750.6		16,271.56
Daily excretion	7,575.06		1,627.16

TABLE 8.—*Digestibility of ration—Period III.*

Constituents and energy.	Total digested.	Digestibility.
	Grams.	*Per cent.*
Dry matter	2,511.9	60.68
Ash	104.3	36.83
Organic matter	2,407.6	62.43
Proteids	262.1	53.48
Nonproteids [a]	60.0	(100.00)
Crude fiber	642.0	53.81
Nitrogen-free extract	1,352.5	68.51
Ether extract	91.0	65.62
Total nitrogen	54.8	60.08
Total carbon	1,131.0	59.18
	Calories.	
Energy	10,869	58.64

[a] Assumed to be wholly digestible.

THE URINARY EXCRETION.

Table IV of the Appendix, based upon the weights recorded in Table I, shows the total amounts of nitrogen, carbon, and potential energy in the urine. In those cases in which some was spilled, the material was taken up as completely as possible with the aid of distilled water and the weight and nitrogen content of the washings determined. It has been assumed that their content of carbon and of energy was proportional to the nitrogen. The following table gives a summary of the average daily excretion:

TABLE 9.—*Average daily excretion in urine—Periods I, II, and III.*

Period.	Nitrogen.	Carbon.	Energy.	Energy per gram of carbon.
	Grams.	*Grams.*	*Calories.*	*Calories.*
I	50.75	112.15	1,046.40	9.33
II	69.05	168.76	1,522.25	9.02
III	60.55	141.80	1,247.16	8.79

It will be observed that the results obtained for the energy per gram of carbon in the urine tend to be rather lower than those found in Kellner's well known experiments, the average being 9.05 calories as compared with 9.6 calories found by Kellner for lean animals. On the basis of later experience, we are inclined to suspect that our estimate of the energy lost in the drying of the samples is somewhat too low. Nevertheless, the discrepancy between our figures and Kellner's is much less than in the previous year and the results have been used as reported.

GROWTH OF EPIDERMAL TISSUE.

The steer was thoroughly brushed each time immediately before entering the calorimeter and after leaving it, and the hair, dandruff, etc., in the latter case collected. To this was added the small amount brushed up from the floor of the calorimeter. In these samples determinations of nitrogen, carbon, and energy were made with the following results, which include for each period the total for the four days during which the animal was in the calorimeter.

TABLE 10.—*Weight and composition of hair, dandruff, etc.—Periods I, II, and III.*

Constituents and energy.	Period I.	Period II.	Period III.	Average.	
				Per period.	Per day.
Weight..............................grams..	29.0	35.3	52.8	....	....
Dry matter......................per cent..	93.10	93.76	93.48	....	....
Weight of dry matter.............grams..	27.0	33.1	49.36	....	....
In dry matter:					
Nitrogen—					
Percentage..........................	4.59	6.31	7.83	....	....
Weight.....................grams..	1.242	2.08	3.86	2.39	0.60
Carbon—					
Percentage..........................	36.716	40.19	42.56	....	....
Weight.....................grams..	9.928	13.30	21.00	14.74	3.39
Energy—					
Per gram.................calories..	4.108	4.533	4.747	....	....
Total.......................calories..	110.91	150.04	234.31	165.10	41.30

As in previous bulletins, it has been assumed that these figures represent the normal rate of production of hair, epidermis, etc., by the animal during the experiment, but not, of course, the matter and energy contained in the growth of hoofs and horns. In the succeeding computations, the averages of Table 10 have been deducted from the gain (*i. e.*, added to the loss) to determine the real gain of flesh and fat, but they have of course been included as a part of the total gain in the final computations of availability.

DETERMINATIONS OF RESPIRATORY PRODUCTS.

As was stated in the introduction, the total metabolism was determined at two different temperatures. For this purpose the animal was placed in the calorimeter on the first and second days and on the eighth and ninth days of the ten-day digestion period proper. During the first of these two respiration experiments the temperature of the calorimeter was kept at 19° C. and during the second at 13.5° C. In the statements which follow the dates given indicate the twenty-four hours ending at 6 p. m. on the date named.

TABLE 11.—*Dates of respiration experiments—Periods I, II, and III.*

Period.	At 19° C.	At 13.5° C.
I	January 13 and 14, 1904	January 20 and 21, 1904.
II	February 10 and 11, 1904	February 17 and 18, 1904.
III	March 9 and 10, 1904	March 16 and 17, 1904.

The respiratory products were determined during forty-eight hours continuously, the time being divided into four subperiods of twelve hours each, the apparatus used being the respiration calorimeter briefly described in Bulletin 51 of this Bureau and more fully in the Experiment Station Record, Vol. XV, p. 1037.

It is impracticable to reproduce here all the details of these determinations. For the general methods employed the reader is referred to the publications just mentioned.

CHECK TESTS.

External air.—As stated in previous bulletins, check tests are depended upon as a means of computing the amount of combustible gases contained in the air as it enters the respiration chamber. The check tests were made at intervals during the experiments here described with the following results:

TABLE 12.—*Combustible gases in external air.*

Date.	Observed volume of air.	Water weighed.	Carbon dioxid weighed.	Per 100 liters dry air at 0° C. and 760 mm.	
				Hydrogen.	Carbon.
	Liters.	*Gram.*	*Gram.*	*Milligram.*	*Milligram.*
January 7, 1904	1,090	0.0135	0.0080	0.153	0.223
January 25, 1904	1,139	.0230	.0080	.243	.208
March 1, 1904	1,090	.0170		.193	
March 21, 1904	941	.0175	.0071	.226	.224
March 21, 1904	892	.0143	.0047	.194	.157
Average				.202	.203

As before, the results are somewhat variable, but in no case are the corrections large as compared with the total amounts determined in the experiments upon the animal.

Alcohol check tests.—The accuracy of the apparatus was tested, as in previous years, by burning in it known amounts of ethyl alcohol and determining the amounts of carbon dioxid, water, and heat evolved. The results of these alcohol check tests as regards carbon dioxid and heat are given below. The results upon water have not yet proven satisfactory.

TABLE 13.—*Results of alcohol check tests.*

Date.	Duration.	Weight of alcohol.		Carbon dioxid.			Heat.		
		Hydrated.	Anhydrous.	Computed.	Observed.	Percentage observed.	Computed.	Observed.	Percentage observed.
	Hours.	*Grams.*	*Grams.*	*Grams.*	*Grams.*		*Calories.*	*Calories.*	
January 5, 1904	6	487.12	436.89	834.90	830.58	99.48	31,253	31,428	100.57
March 25, 1904	7	541.68	485.82	928.40	907.51	97.74	34,753	35,490	102.13

It will be noted that the agreement of the results in the test of January 5 is very satisfactory, while in that of March 25 a somewhat greater departure from the theoretical results occurred.

RESULTS UPON THE ANIMAL.

Tables V, VI, VII, VIII, IX, and X of the Appendix contain the results of the determinations of the respiratory products for the several periods and subperiods. These are summarized in the table following:

TABLE 14.—*Excreted in respiration.*

Period and subperiod.	Carbon as CO_2.	Carbon as CH_4.	Water.
Period I*a*:	*Grams.*	*Grams.*	*Grams.*
Subperiod 1	533.15	25.97	1,979.72
Subperiod 2	530.01	23.20	2,048.84
First day	1,063.16	49.17	4,028.56
Subperiod 3	542.45	25.40	1,925.27
Subperiod 4	552.44	27.39	1,886.38
Second day	1,094.89	52.79	3,811.65
Average	1,079.03	50.98	3,920.11
Period I*b*:			
Subperiod 1	533.80	25.36	1,242.85
Subperiod 2	539.19	23.24	1,395.35
First day	1,072.99	48.60	2,638.20
Subperiod 3	545.31	25.73	1,377.35
Subperiod 4	566.16	23.14	1,498.50
Second day	1,111.47	48.87	2,875.85
Average	1,092.23	48.74	2,757.03
Period II*a*:			
Subperiod 1	605.68	31.40	2,270.10
Subperiod 2	642.34	41.68	2,395.53
First day	1,248.02	73.08	4,665.63
Subperiod 3	642.50	38.45	2,377.88
Subperiod 4	628.97	25.43	2,358.17
Second day	1,271.47	63.88	4,736.05
Average	1,259.75	68.48	4,700.84
Period II*b*:			
Subperiod 1	615.27	19.72	1,684.21
Subperiod 2	622.32	22.05	1,649.37
First day	1,237.59	41.77	3,333.58
Subperiod 3	622.96	31.20	1,782.71
Subperiod 4	618.04	(?)	1,772.73
Second day	1,241.00	....	3,555.44
Average	1,239.30	48.64	3,444.51

TABLE 14.—*Excreted in respiration*—Continued.

Period and subperiod.	Carbon as CO_2.	Carbon as CH_4.	Water.
Period III*a*:	*Grams.*	*Grams.*	*Grams.*
Subperiod 1	587.26	[a] 28.03	2,349.54
Subperiod 2	568.68	[a] 34.07	2,283.50
First day	1,155.94	[a] 62.10	4,633.04
Subperiod 3	581.71	25.08	2,185.98
Subperiod 4	563.11	27.36	2,364.54
Second day	1,144.82	52.44	4,550.52
Average	1,150.38	....	4,591.78
Period III*b*:			
Subperiod 1	568.23	24.13	1,756.48
Subperiod 2	560.76	31.28	1,622.86
First day	1,128.99	55.41	3,379.34
Subperiod 3	568.89	31.94	1,693.32
Subperiod 4	572.29	34.35	1,851.48
Second day	1,141.18	66.29	3,544.80
Average	1,135.09	60.85	3,462.07

[a] Includes a correction for the time during which the gas supply of the combustion furnaces was cut off.

Hydrocarbon gases.—In the experiment with timothy hay in 1901–2 it was shown that the ratio of hydrogen to carbon in the combustible gases given off by the animal was almost identical with that for methane, while in the experiment of the succeeding year it was appreciably lower. The corresponding results for the present experiment were as follows:

TABLE 15.—*Composition of combustible gases.*

Period and subperiod.	Hydrogen.	Carbon.	Ratio of hydrogen to carbon.	Methane computed from carbon.
Period I*a*:	*Grams.*	*Grams.*		*Grams.*
Subperiod 1	8.03	25.97	1:3.234	34.70
Subperiod 2	7.23	23.20	1:3.209	31.00
First day	15.26	49.17	1:3.225	65.70
Subperiod 3	8.02	25.40	1:3.167	33.94
Subperiod 4	8.69	27.39	1:3.152	36.59
Second day	16.71	52.79	1:3.159	70.53
Average	15.99	50.98	1:3.188	68.11
Period I*b*:				
Subperiod 1	7.67	25.36	1:3.306	33.88
Subperiod 2	7.06	23.24	1:3.292	31.05
First day	14.73	48.60	1:3.299	64.93
Subperiod 3	8.49	25.73	1:3.031	34.38
Subperiod 4	7.15	23.14	1:3.237	30.92
Second day	15.64	48.87	1:3.125	65.30
Average	15.19	48.74	1:3.209	65.12

TABLE 15.—*Composition of combustible gases*—Continued.

Period and subperiods.	Hydrogen.	Carbon.	Ratio of hydrogen to carbon.	Methane computed from carbon.
	Grams.	*Grams.*		*Grams.*
Period II*a*:				
Subperiod 1	9.92	31.40	1:3.165	41.95
Subperiod 2	13.19	41.68	1:3.160	55.69
First day	23.11	73.08	1:3.162	97.64
Subperiod 3	12.36	38.45	1:3.111	51.37
Subperiod 4	7.91	25.43	1:3.215	33.98
Second day	20.27	63.88	1:3.151	85.35
Average	21.69	68.48	1:3.157	91.49
Period II*b*:				
Subperiod 1	6.09	19.72	1:3.238	26.35
Subperiod 2	7.43	22.05	1:2.968	29.46
First day	13.52	41.77	1:3.090	55.81
Subperiod 3	9.79	31.20	1:3.187	41.68
Subperiod 4	(?)	(?)	....	....
Second day	....	....	....	....
Average	....	....	....	....
Period III*a*:				
Subperiod 1	[a]8.89	[a]28.03	1:3.153	37.45
Subperiod 2	[a]10.88	[a]34.07	1:3.131	45.52
First day	19.77	62.10	1:3.141	82.97
Subperiod 3	7.89	25.08	1:3.179	33.51
Subperiod 4	8.63	27.36	1:3.171	36.55
Second day	16.52	52.44	1:3.174	70.06
Average	18.15	57.27	1:3.155	76.52
Period III*b*:				
Subperiod 1	7.26	24.13	1:3.324	32.24
Subperiod 2	10.03	31.28	1:3.119	41.79
First day	17.29	55.41	1:3.205	74.03
Subperiod 3	10.40	31.94	1:3.071	42.67
Subperiod 4	11.06	34.35	1:3.106	45.89
Second day	21.46	66.29	1:3.089	88.56
Average	19.38	60.85	1:3.140	81.30

[a] Includes a correction.

It will be observed that in every instance the ratio of hydrogen to carbon is lower than that in methane. The average ratio for all the periods is almost exactly the same as that found in the experiments of the previous year, as reported in Bulletin 74 of this Bureau, viz, 1:3.17, which corresponds to the following composition as compared to the theoretical:

	Found.	In methane.
	Per cent.	*Per cent.*
Carbon	76.02	74.85
Hydrogen	23.98	25.15
	100.00	100.00

The presence of free hydrogen in the intestinal gases of animals has occasionally been noted, but it is difficult to see what compound richer in carbon than methane would be likely to be present. In the light of subsequent experience, we are inclined to suspect that insufficient heating of the platinized kaolin may be responsible for the deficiency of hydrogen. At any rate, pending a critical study of the method employed, we have for the present computed the excretion of methane from the amounts of carbon shown in the above table.

The results of Period II*b*, it will be noted, are exceedingly low, and none at all are reported for subperiod 4 of this period. In the subsequent computations, therefore, these results have been rejected and those obtained in Period II*a*, on the same ration, employed.

DETERMINATIONS OF HEAT.

It is impracticable to reproduce here the very voluminous records required for the determination of the heat produced, and it must suffice to indicate the general method and to summarize the main results.

As explained in Bulletin 51, the heat given off by the animal as sensible heat is removed from the apparatus by a water current, the amount thus removed being measured by the product of the amount of water passing through the absorbers and the rise in temperature during its passage through the apparatus. As noted, the temperature of the water is taken every four minutes, while the efflux of each 100 liters is noted on the records. In any portion of the experiment during which the rate of flow of water is uniform we may, without sensible error, compute the averages of the ingoing and of the outcoming temperatures and multiply the total weight of water by the difference between the two. Certain corrections are necessary, however.

First. The pipe composing our absorber being of small diameter, there is a not inconsiderable pressure upon the bulbs of the thermometers, and this pressure varies with the rate at which the water flows. Since the pressure is greater upon the ingoing than upon the outcoming thermometer, the effect is to render the observed difference in temperature too small. A correction for this effect has been worked out experimentally for the range of pressure used and is applied in the table.

Second. The friction of the water in the absorbers is itself the source of a small amount of heat, which is computed from the difference in pressure at entrance and exit and the weight of the water passing through the absorbers.

Third. As Atwater and Rosa have shown, it is essential to take account of the variation in the specific heat of water at different temperatures. We have followed their practice, and, assuming the specific heat of water at 20° C. as unity, have expressed all our results in calories at 20°, using for this purpose the table of the specific heat of water given by those observers.[a]

Fourth. Corrections have to be made for the heat introduced into the apparatus or withdrawn from it in case the feed, drink, excreta, and vessels containing them are introduced or removed at a temperature different from that of the calorimeter. The net amount of these corrections, as appears from the table, is ordinarily small, but the single factors are sometimes not inconsiderable. This is especially the case with the feces, where considerable difficulty has been experienced in determining the true average temperature of the mass.

The results of these several computations are contained in Table XI of the Appendix. To the heat thus measured is to be added the latent heat of water vapor evaporated in and carried out of the chamber. This is computed from the results for water, assuming the latent heat of vaporization to be 0.592 calorie per gram.

The following table contains a summary of the amounts of heat measured in the calorimeter in the several periods and subperiods. By a series of accidents the results for Period II*b*, subperiods 3 and 4, were rendered valueless.

TABLE 16.—*Heat measured in calorimeter.*

	Period I*a*.	Period I*b*.	Period II*a*.	Period II*b*.	Period III*a*.	Period III*b*.
First day:	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*
Subperiod 1	5,667.92	5,827.99	5,765.91	5,773.06	5,586.97	5,683.14
Subperiod 2	5,213.80	....	5,639.28	5,300.77	5,322.91	5,115.06
Total	10,881.72	....	11,405.19	11,073.83	10,909.88	10,798.20
Second day:						
Subperiod 3	5,522.33	5,956.95	5,901.96	....	5,324.48	5,345.11
Subperiod 4	5,605.56	5,739.96	5,721.91	....	5,350,96	5,561.71
Total	11,127.89	11,696.91	11,623.87	....	10,675.44	10,906.82
Average per day	11,004.8	....	11,514.53	....	10,792.66	10,852.5

RATE OF HEAT EMISSION.

As in previous experiments, the rate at which heat was emitted by the animal varied notably according as the animal was standing or lying. The following table shows the total heat emitted during the periods of standing and lying, respectively. The figures of this table relate only to the amount of heat given off by radiation and conduction and removed from the calorimeter in the water current, and do not include the heat carried off as latent heat of water vapor.

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[a] U. S. Department of Agriculture, Office of Experiment Stations Bulletin 63, p. 56.

TABLE 17.—*Heat emission, standing and lying.*

Period and subperiod.	Time.	Position.	Total heat.	Heat per minute.
Period I*a*:				
Subperiod 1—	*Minutes.*		*Calories.*	*Calories.*
6.00 p. m. to 11.59 p. m.	359	Standing	2,228.63	6.2079
11.59 p. m. to 2.13 a. m.	134	Lying	639.07	4.7691
2.13 a. m. to 6.00 a. m.	227	Standing	1,628.23	7.1728
Subperiod 2—				
6.00 a. m. to 9.44 a. m.	224	Standing	1,329.16	5.9333
9.44 a. m. to 11.39 a. m.	115	Lying	471.06	4.0961
11.39 a. m. to 6.00 p. m.	381	Standing	2,200.67	5.7760
Subperiod 3—				
6.00 p. m. to 7.46 p. m.	106	Standing	652.54	6.1560
7.46 p. m. to 7.51 p. m.	5	Lying	26.50	5.3000
7.51 p. m. to 12.58 a. m.	307	Standing	1,967.26	6.4080
12.58 a. m. to 3.08 a. m.	130	Lying	581.58	4.4737
3.08 a. m. to 6.00 a. m.	172	Standing	1,154.69	6.7133
Subperiod 4—				
6.00 a. m. to 6.00 p. m.	720	Standing	4,488.83	6.2344
Period II*a*:				
Subperiod 1—				
6.00 p. m. to 2.36 a. m.	516	Standing	3,347.84	6.4880
2.36 a. m. to 5.01 a. m.	145	Lying	643.67	4.4390
5.01 a. m. to 6.00 a. m.	59	Standing	430.50	7.2796
Subperiod 2—				
6.00 a. m. to 9.41 a. m.	221	Standing	1,440.59	6.5185
9.41 a. m. to 12.46 p. m.	185	Lying	797.73	4.3120
12.46 p. m. to 2.46 p. m.	120	Standing	856.32	7.1360
2.46 p. m. to 4.29 p. m.	103	Lying	413.74	4.0169
4.29 p. m. to 6.00 p. m.	91	Standing	712.75	7.8320
Subperiod 3—				
6.00 p. m. to 8.55 p. m.	175	Standing	1,199.09	6.8519
8.55 p. m. to 10.42 p. m.	107	Lying	521.08	4.8699
10.42 p. m. to 2.05 a. m.	203	Standing	1,448.46	7.1352
2.05 a. m. to 4.33 a. m.	148	Lying	689.35	4.6577
4.33 a. m. to 6.00 a. m.	87	Standing	636.28	7.3135
Subperiod 4—				
6.00 a. m. to 8.12 a. m.	132	Standing	868.59	6.5802
8.12 a. m. to 10.36 a. m.	144	Lying	632.67	4.3935
10.36 a. m. to 1.07 p. m.	151	Standing	1,054.01	6.9802
1.07 p. m. to 2.49 p. m.	102	Lying	479.26	4.6986
2.49 p. m. to 6.00 p. m.	191	Standing	1,291.34	6.7609
Period III*a*:				
Subperiod 1—				
6.00 p. m. to 8.57 p. m.	177	Standing	1,079.26	6.0975
8.57 p. m. to 9.36 p. m.	39	Lying	160.94	4.1266
9.36 p. m. to 2.53 a. m.	317	Standing	2,005.17	6.3240
2.53 a. m. to 4.58 a. m.	125	Lying	541.65	4.3332
4.58 a. m. to 6.00 a. m.	62	Standing	409.02	6.5971
Subperiod 2—				
6.00 a. m. to 8.31 a. m.	151	Standing	939.75	6.2235
8.31 a. m. to 10.10 a. m.	99	Lying	346.29	3.4978
10.10 a. m. to 11.46 a. m.	96	Standing	649.32	6.7637
11.46 a. m. to 2.27 p. m.	161	Lying	680.80	4.2285
2.27 p. m. to 6.00 p. m.	213	Standing	1,354.92	6.3611
Subperiod 3—				
6.00 p. m. to 7.46 p. m.	106	Standing	663.16	6.2562
7.46 p. m. to 9.20 p. m.	94	Lying	427.21	4.5448
9.20 p. m. to 10.24 p. m.	64	Standing	447.00	6.9843
10.24 p. m. to 11.58 p. m.	94	Lying	426.67	4.5390
11.58 p. m. to 12.25 a. m.	27	Standing	192.46	7.1281
12.25 a. m. to 2.09 a. m.	104	Lying	489.88	4.7103
2.09 a. m. to 3.04 a. m.	55	Standing	432.65	7.8663
3.04 a. m. to 4.59 a. m.	115	Lying	563.52	4.9001
4.59 a. m. to 6.00 a. m.	61	Standing	387.83	6.3578
Subperiod 4—				
6.00 a. m. to 9.30 a. m.	210	Standing	1,295.38	6.1685
9.30 a. m. to 11.36 a. m.	126	Lying	522.45	4.1464
11.36 a. m. to 1.37 p. m.	121	Standing	757.97	6.2642
1.37 p. m. to 3.56 p. m.	139	Lying	560.45	4.0320
3.56 p. m. to 6.00 a. m.	124	Standing	814.90	6.5720
Period I*b*:				
Subperiod 1—				
6.00 p. m. to 6.00 a. m.	720	Standing	5,092.23	7.0725
Subperiod 2—				
6.00 a. m. to 6.00 p. m.	720	Standing		
Subperiod 3—				
6.00 p. m. to 6.00 a. m.	720	Standing	5,141.56	7.1411
Subperiod 4—				
6.00 a. m. to 6.00 p. m.	720	Standing	4,852.85	6.7401

TABLE 17.—*Heat emission, standing and lying*—Continued.

Period and subperiod.	Time.	Position.	Total heat.	Heat per minute.
Period II*b*:				
Subperiod 1—	*Minutes.*		*Calories.*	*Calories.*
6.00 p. m. to 1.51 a. m	471	Standing	3,271.84	....
1.51 a. m. to 1.56 a. m	5	Lying	32.56	6.5120
1.56 a. m. to 3.29 a. m	93	Standing	665.08	7.1514
3.29 a. m. to 5.46 a. m	137	Lying	690.83	5.0425
5.46 a. m. to 6.00 a. m	14	Standing	115.70	8.2642
Subperiod 2—				
6.00 a. m. to 1.14 p. m	434	Standing	2,648.94	6.1035
1.14 p. m. to 3.26 p. m	132	Lying	581.85	4.4075
3.26 p. m. to 6.00 p. m	154	Standing	1,093.56	7.1010
Subperiod 3—				
6.00 p. m. to 7.59 p. m	119	Standing	788.46	6.6257
7.59 p. m. to 10.38 p. m	159	Lying	861.70	5.4195
10.38 p. m. to 11.42 p. m	64	Standing	485.74	7.5896
11.42 p. m. to 1.51 a. m	129	Lying	739.81	5.7349
1.51 a. m. to 5.17 a. m	206	Standing and lying.[a]	1,192.22	([a])
5.17 a. m. to 6.00 a. m	43	Standing	333.94	7.7660
Subperiod 4—				
6.00 a. m. to 8.59 a. m	179	Standing	1,231.48	6.8797
8.59 a. m. to 10.26 a. m	87	Lying	454.05	5.2189
10.26 a. m. to 1.24 p. m	178	Standing	1,202.65	6.7564
1.24 p. m. to 2.20 p. m	56	Lying	260.11	4.6448
2.20 p. m. to 6.00 p. m	220	Standing	1,590.73	7.2305
Period III*b*:				
Subperiod 1—				
6.00 p. m to 10.27 p. m	267	Standing	1,815.36	6.7991
10.27 p. m. to 12.21 a. m	114	Lying	574.49	5.0394
12.21 a. m. to 2.05 a. m	104	Standing	751.12	7.2223
2.05 a. m. to 3.31 a. m	86	Lying	457.29	5.3173
3.31 a. m. to 6.00 a.m	149	Standing	1,045.05	7.0137
Subperiod 2—				
6.00 a. m. to 10.33 a. m	273	Standing	1,587.45	5.8148
10.33 a. m. to 12.33 p. m	120	Lying	551.84	4.5986
12.33 p. m. to 1.54 p. m	81	Standing	497.03	6.1361
1.54 p. m. to 2.44 p. m	50	Lying	215.99	4.3198
2.44 p. m. to 6.00 p. m	196	Standing	1,302.02	6.6428
Subperiod 3—				
6.00 p. m. to 8.07 p. m	127	Standing	792.55	6.2405
8.07 p. m. to 9.30 p. m	83	Lying	394.36	4.7513
9.30 p. m. to 1.25 a. m	235	Standing	1,612.37	6.8611
1.25 a. m. to 2.58 a. m	93	Lying	483.30	5.1967
2.58 a. m. to 3.47 a. m	49	Standing	312.72	6.3820
3.47 a. m. to 5.44 a. m	117	Lying	608.25	5.1987
5.44 a. m. to 6.00 a. m	16	Standing	139.12	8.6950
Subperiod 4—				
6.00 a. m. to 9.18 a. m	198	Standing	1,286.64	6.4981
9.18 a. m. to 11.28 a. m	130	Lying	574.65	4.4203
11.28 a. m. to 1.43 p. m	135	Standing	927.79	6.8725
1.43 p. m. to 1.45 p. m	2	Lying	2.38	1.1900
1.45 p. m. to 6.00 p. m	255	Standing	1,674.18	6.5654

[a] The animal lay down so quietly that it was not noticed at the time. Therefore no division was made between 1.51 and 5.17 for standing and lying.

From the foregoing table have been computed the following results for the total heat emitted during the several periods in the lying and the standing positions, respectively, together with the average heat emission per minute. In making these computations the artificial division into subperiods has been disregarded.

TABLE 18.—*Average heat emission per minute.*

	Lying.	Standing.
Period I*a*:		
Minutes	384	2,496
Total heat ..calories	1,718.2	15,650.0
Heat per minute ..do	4.4747	6.2700
Ratio	1	1.4012
Period II*a*:		
Minutes	934	1,946
Total heat ..calories	4,177.5	13,285.8
Heat per minute ..do	4.4727	6.8272
Ratio	1	1.5264
Period III*a*:		
Minutes	1,096	1,784
Total heat ..calories	4,719.8	11,428.7
Heat per minute ..do	4.3064	6.4062
Ratio	1	1.4876
Period I*b* (subperiods 1, 3, and 4):		
Minutes		2,160
Total heat ..calories		15,086.64
Heat per minute ..do		6.9846
Period II*b* (subperiods 1 and 2 only):		
Minutes	274	1,166
Total heat ..calories	1,305.2	7,802.2
Heat per minute ..do	4.7636	6.6914
Ratio	1	1.4047
Period III*b*:		
Minutes	795	2,085
Total heat ..calories	3,862.5	13,743.4
Heat per minute ..do	4.8585	6.5915
Ratio	1	1.3566

The differences in rate of heat emission, although slightly smaller, are still quite comparable with those observed in the previous year with the same animal (Bul. 74, p. 24), while both are larger than those observed in the first year's experiments (Bul. 51, p. 37). In the results of the last two years there appears a distinct effect of the amount of feed consumed, the difference in the heat emission standing and lying tending to be greater on the heavier rations. In this year's experiments, too, the difference seems to be less in the trials at the lower temperature, although the results for periods I*b* and II*b*, as noted, are somewhat incomplete. While we should naturally ascribe these differences in heat emission chiefly to the increased muscular exertion required in standing, it would seem that there are other factors affecting it.

HEAT EMISSION AND HEAT PRODUCTION.

The figures of the preceding tables show the amounts of heat given off by the animal. The heat emitted by the animal, however, is equal to the amount of heat actually produced only when the initial and final states of the animal are the same. Consequently there may be, according to circumstances, either a storage of heat in the body or an emission of heat produced in a previous period. In this respect there are two principal sources of error—first, variations in the body temperature of the animal; second, a storage or loss of matter by the body. As regards the first of these sources of error, it has been assumed that under normal and uniform conditions the body temperature would be substantially the same at the same hour of the day. We have not been able as yet to make systematic determinations of the body temperature of cattle as a check upon this assumption, but the rectal temperature of the animal was taken daily during the digestion periods proper of Periods I and II, except when the steer was in the calorimeter, and also during the preliminary feeding of Periods II and III, and on one day during the digestion period proper of Period III. The observations were made immediately before watering, by means of a self-registering mercurial thermometer, with the following results:

TABLE 19.—*Temperature of the animal.*

Period I.		Period II.		Period III.	
Date.	Temperature.	Date.	Temperature.	Date.	Temperature.
	°*C.*		°*C.*		°*C.*
January 15	38.3	February 3	38.3	February 28	38.2
16	38.1	4	38.2	29	38.3
17	38.1	5	38.2	March 1	38.3
18	38.2	6	38.2	2	38.4
19	37.9	7	38.3	3	38.3
22	38.0	8	38.2	4	38.3
		9	38.1	5	38.2
Average	38.1	12	38.1	6	38.3
		13	38.2	7	38.3
		14	38.1	12	38.3
		15	38.2	Average	38.3
		16	38.1		
		19	38.3		
		Average	38.2		

In but two cases does the difference between two successive days exceed 0.1° C. With an average live weight of about 580 kilograms, assuming a specific heat of 0.8 for the body, this difference is equivalent to 46 calories.

If the animal stores up matter in its body, there must necessarily be a corresponding retention of a portion of the heat arising from body metabolism, since the matter which is stored was consumed in the food at a temperature considerably below that of the body. On the other hand, if there is a loss of matter from the body in any one of the various excreta, the temperature of this matter is reduced (either actually or by calculation) to that of the surrounding air before it leaves the calorimeter, and this heat which was previously stored up in the body is measured along with that actually produced during the experiment. The above statements are of course true whatever be the kind of matter stored up or given off; but the income and outgo of water is of especial importance in this respect, both because of its large amount and because of the high specific heat of water. Indeed, a very simple calculation serves to show that in these experiments the difference in the income and outgo of dry matter does not materially affect the computation of the balance of energy, and that consequently only the income and outgo of water need be considered.

From the data contained in the various tables of the Appendix are compiled the following tables, showing the income and outgo of water by the animal and the corresponding gain or loss of heat on each day of the calorimeter experiments. The body temperature has been assumed to be represented by the average for the period (Table 19), while that of the calorimeter was 19.0° C. and 13.5° C. in the series *a* and *b*, respectively, except in Period III*b*, when it was 13.8° C. In the case of feces spilled in the calorimeter the water remaining in them when sampled has been divided equally between the two days.

TABLE 20.—*Approximate water balance.*

PERIOD I.

	Income.	Outgo.		Income.	Outgo.
Period I*a*:			Period I*b*:		
January 13—	*Grams.*	*Grams.*	January 20—	*Grams.*	*Grams.*
Hay	272		Hay	289	
Water	11,330		Water	3,554	
Feces		2,908	Feces		4,936
Feces spilled		37	Feces spilled		4
Urine		3,963	Urine		3,599
Water vapor		4,029	Water vapor		2,638
Balance		665	Balance	7.334	
	11,602	11,602		11,177	11,177
January 14—			January 21—		
Hay	296		Hay	270	
Water	760		Water	11,895	
Feces		4,718	Feces		5,102
Feces spilled		37	Feces spilled		4
Urine		2,984	Urine		2,583
Water vapor		3,812	Water vapor		2,876
Balance	10,495		Balance		1,600
	11,551	11,551		12,165	12.165

PERIOD II.

	Income.	Outgo.		Income.	Outgo.
Period II*a*:			Period II*b*:		
February 10—			February 17—		
Hay	536		Hay	449	
Water	11,952		Water	25,670	
Feces		9,856	Feces		7,658
Feces spilled		54	Feces spilled		14
Urine		5,209	Urine		5,242
Water vapor		4,666	Water vapor		3,334
Balance	7,297		Balance		9,871
	19,785	19,785		26,119	26,119
February 11—			February 18—		
Hay	597		Hay	504	
Water	17,470		Water	14,460	
Feces		8,696	Feces		6,921
Feces spilled		54	Feces spilled		14
Urine		5,584	Urine		5,071
Water vapor		4,736	Water vapor		3,560
Balance	1,003		Balance	602	
	19,070	19,070		15,566	15,566

TABLE 20.—*Approximate water balance*—Continued.

PERIOD III.

	Income.	Outgo.		Income.	Outgo.
Period III*a*:			Period III*b*:		
March 9—	*Grams.*	*Grams.*	March 16—	*Grams.*	*Grams.*
Hay	458		Hay	412	
Water	5,205		Water	18,100	
Uneaten residue		99	Feces		6,611
Feces		5,762	Feces spilled		4
Feces spilled		7	Urine		4,461
Urine		4,578	Water vapor		3,379
Water vapor		4,633	Balance		4,057
Balance	9,416				
	15,079	15,079		18,512	18,512
March 10—			March 17—		
Hay	451		Hay	387	
Water	16,020		Water	11,200	
Uneaten residue		53	Feces		5,779
Feces		5,100	Feces spilled		4
Feces spilled		7	Urine		4,548
Urine		4,503	Water vapor		3,545
Water vapor		4,551	Balance	2,289	
Balance		2,257			
	16,471	16,471		13,876	13,876

Upon the basis of the above figures the actual heat production has been computed, as shown in the following table, the difference between the income and outgo of water, expressed in kilograms, being multiplied by the difference between the average body temperature for the period and the temperature of the calorimeter to obtain the correction. With the exception of Period II*a*, the results for the two days of each period where such a comparison is possible show a very close agreement in the amount of heat actually produced.

TABLE 21.—*Heat production.*

Period.	Measured in calorimeter.	Correction for water balance.	Heat produced.
Period I*a*:	*Calories.*	*Calories.*	*Calories.*
First day	10,881.7	+ 12.7	10,894.4
Second day	11,127.9	−200.5	10,927.4
Average	11,004.8	− 93.9	10,910.9
Period I*b*:			
First day			
Second day	11,696.9	+ 39.4	11,736.3
Period II*a*:			
First day	11,405.2	−140.1	11,265.1
Second day	11,623.9	− 19.3	11,604.6
Average	11,514.5	− 79.7	11,434.9
Period II*b*:			
First day	11,073.8	+243.8	11,317.6
Second day			
Period III*a*:			
First day	10,909.9	−181.7	10,728.2
Second day	10,675.4	+ 43.6	10,719.0
Average	10,792.7	− 69.1	10,723.6
Period III*b*:			
First day	10,798.2	+ 99.4	10,897.6
Second day	10,906.8	− 56.1	10,850.7
Average	10,852.5	+ 21.7	10,874.2

THE BALANCE OF MATTER.

Considering the figures for epidermal tissues in Table 10 to represent the average rate of growth of hair, etc., we may subdivide the gain or loss as ordinarily computed into the growth of these tissues and the real gain or loss of the proteids and fat of the body, as has been done in the computations which follow.

THE NITROGEN AND CARBON BALANCE.

The income and outgo of nitrogen and carbon are shown in the following table. The figures for hydrogen are omitted for the reason that, as stated on page 15, the results for water were not found to be entirely satisfactory. In Period II*b*, as noted on page 19, the results on methane were apparently too low, and therefore those of Period II*a*, on the same ration, have been substituted.

TABLE 22.—*Income and outgo of nitrogen and carbon per day and head.*

Period.	Nitrogen.		Carbon.	
	Income.	Outgo.	Income.	Outgo.
	Grams.	*Grams.*	*Grams.*	*Grams.*
Period I*a*:				
Hay	65.12		1,363.70	
Feces		25.85		546.98
Urine		50.75		112.15
Brushings		0.60		3.69
Methane				50.98
Carbon dioxid				1,079.03
Balance	12.08		429.13	
	77.20	77.20	1,792.83	1,792.83
Period I*b*:				
Hay	65.12		1,363.70	
Feces		25.85		546.98
Urine		50.75		111.61
Brushings		0.60		3.69
Methane				48.74
Carbon dioxid				1,092.38
Balance	12.08		439.70	
	77.20	77.20	1,803.40	1,803.40
Period II*a*:				
Hay	112.06		2,323.71	
Feces		43.45		931.83
Urine		69.05		168.76
Brushings		0.60		3.69
Methane				68.48
Carbon dioxid				1,259.75
Balance	1.04		108.80	
	113.10	113.10	2,432.51	2,432.51
Period II*b*:				
Hay	112.06		2,323.71	
Feces		43.45		931.83
Urine		69.05		168.76
Brushings		0.60		3.69
Methane				68.48
Carbon dioxid				1,239.30
Balance	1.04		88.35	
	113.02	113.02	2,412.06	2,412.06

TABLE 22.—*Income and outgo of nitrogen and carbon per day and head*—Continued.

Period.	Nitrogen.		Carbon.	
	Income.	Outgo.	Income.	Outgo.
Period IIIa:	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Hay	91.47		1,911.04	
Feces		36.44		780.05
Urine		60.55		141.80
Brushings		0.60		3.69
Methane				57.27
Carbon dioxid				1,150.38
Balance	6.12		222.15	
	97.59	97.59	2,133.19	2,133.19
Period IIIb:				
Hay	91.47		1,911.04	
Feces		36.44		780.05
Urine		60.55		141.80
Brushings		0.60		3.69
Methane				60.85
Carbon dioxid				1,135.09
Balance	6.12		210.44	
	97.59	97.59	2,121.48	2,121.48

GAIN OF PROTEIN AND FAT.

Excluding the brushings, the gain of protein and fat, which was of course negative in every instance, has been computed in the usual manner, using Köhler's[a] figures for the composition of the nitrogenous tissue of cattle, namely, nitrogen 16.67 per cent and carbon 52.54 per cent. In other words, body protein is equivalent to nitrogen multiplied by 6. In the computation of fat from carbon the usual factor (1.3) has been employed.

TABLE 23.—*Gain of protein and fat per day and head.*

Period.	Gain of nitrogen.	Equivalent protein (N×6).	Gain of carbon.			Equivalent gain of fat.	Computed energy of gain.		
			Total.	As protein.	As fat.		Protein.	Fat.	Total.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Calories.*	*Calories.*	*Calories.*
Ia	−12.08	−72.48	−429.13	−38.08	−391.05	−508.4	−413.2	−4,829.8	−5,243.0
Ib	−12.08	−72.48	−439.70	−38.08	−401.62	−522.2	−413.2	−4,960.9	−5,374.1
IIa	− 1.04	− 6.24	−108.80	− 3.28	−105.52	−137.2	− 35.6	−1,303.4	−1,339.0
IIb	− 1.04	− 6.24	− 88.35	− 3.28	− 85.07	−110.6	− 35.6	−1,050.7	−1,086.3
IIIa	− 6.12	−36.72	−222.15	−19.29	−202.86	−263.7	−209.3	−2,505.2	−2,714.5
IIIb	− 6.12	−36.72	−210.44	−19.29	−191.15	−248.5	−209.3	−2,360.8	−2,570.1

THE BALANCE OF ENERGY.

In these experiments we have direct determinations of all the factors of income and outgo of energy, except the potential energy of the methane excreted and that of the tissue gained by the animal. The energy of the methane, however, may be safely computed from its amount, its heat of combustion at constant pressure being 13.344 calories per gram. The energy of the gain of tissue by the animal may be estimated in the usual way from the computed amounts of protein and fat given above, using the factors 5.7 calories and 9.5 calories per gram, respectively. Having done this, we are in position to compare the income with the outgo of energy, and thus to check to a considerable extent the accuracy of our experiments. The following table contains such a comparison for each period. The difference between income and outgo, which has been entered in the table under the heading "Error," shows, of course, the extent to which our results appear to deviate from those required by the law of the conservation of energy.

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[a] Zeit. f. Physiol. Chem., 31, 479.

TABLE 24.—*Balance of energy per day and head.*

	Period I.		Period II.		Period III.	
	Income.	Outgo.	Income.	Outgo.	Income.	Outgo.
	Calories.	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*
Series *a*, at 19° C.:						
Hay	13,170.7		22,557.7		18,535.1	
Feces		5,403.3		9,132.0		7,666.1
Urine		1,046.4		1,522.3		1,247.2
Brushings		41.3		41.3		41.3
Methane		908.9		1,221.0		1,021.0
Heat		10,910.9		11,434.9		10,723.6
Loss by body—						
Proteids	413.2		35.6		209.3	
Fat	4,829.8		1,303.4		2,505.2	
Error		102.9		545.2		550.4
	18,413.7	18,413.7	23,896.7	23,896.7	21,249.6	21,249.6
Series *b*, at 13.5° C.:						
Hay	13,170.7		22,557.7		18,535.1	
Feces		5,403.3		9,132.0		7,666.1
Urine		1,046.4		1,522.3		1,247.2
Brushings		41.3		41.3		41.3
Methane		868.9		[a]1,221.0		1,084.8
Heat		11,736.3		11,317.6		10,874.6
Loss by body—						
Proteids	413.2		35.6		209.3	
Fat	4,960.9		1,050.7		2,560.8	
Error	551.4			409.8		191.2
	19,096.2	19,096.2	23,644.0	23,644.0	21,105.2	21,105.2

[a] Assumed to be the same as in Period II*a*. See p. 19.

With the exception of Periods I*a* and III*b*, the agreement between the results computed from the energy balance and those computed from the balance of carbon and nitrogen is much less satisfactory than in previous years. A direct comparison of the gains or losses, however, is somewhat misleading, because all the errors of the experiments are concentrated in a single relatively small number. It seems on the whole fairer, therefore, to compare the total heat production as measured with that computed from the balance of carbon and nitrogen, as has been done in the following table:

TABLE 25.—*Heat production per day and head.*

Period.	Computed.	Observed.	Computed÷observed.
	Calories.	*Calories.*	*Per cent.*
I*a*	11,012.9	10,910.9	100.9
I*b*	11,184.9	11,786.3	95.3
II*a*	11,980.1	11,434.9	104.8
II*b*	11,727.4	11,317.6	103.6
III*a*	11,274.0	10,723.6	105.1
III*b*	11,065.8	10,874.6	101.8

The computed heat production exceeds more or less that actually observed in every instance but one. This is practically equivalent to saying either that the results for the carbon excretion are too high, or those for heat too low, or else that some nonnitrogenous body substance other than fat was being oxidized. As regards the first alternative it may be said that according to the results of our alcohol check tests in each year the tendency of the apparatus seems to be in precisely the opposite direction, viz, to give results slightly too low for carbon dioxid and too high for heat. As regards the nature of the body substances oxidized, it is of course possible that it may have consisted in part of stored-up carbohydrates (glycogen) which would evolve more CO_2 in proportion to the energy liberated than would fat. It is hardly possible, however, that this can have been the case to the large extent required to account for the observed discrepancies.

It should be noted further that the results in Periods II*b* and III*b* are somewhat uncertain, owing to various disturbances during the runs.

DISCUSSION OF RESULTS.

DIGESTIBILITY.

The results tabulated in Table III of the Appendix and summarized also under the several periods are brought together in the following table:

TABLE 26.—*Percentage digestibility.*

Constituents and energy.	Period I.	Period II.	Period III.
	Per cent.	*Per cent.*	*Per cent.*
Dry matter	61.41	61.39	60.68
Ash	44.04	40.92	36.83
Organic matter	62.70	62.96	62.43
Proteids	54.56	54.08	53.48
Nonproteids	[a] 100.00	[a] 100.00	[a] 100.00
Crude fiber	55.37	55.97	53.81
Nitrogen-free extract	68.05	67.90	68.51
Ether extract	62.24	64.08	65.62
Energy	58.97	59.51	58.64

[a] Assumed.

The slight differences between the several periods attest the accuracy of this part of the experiment.

METABOLIZABLE ENERGY.

The term metabolizable energy has been used by the writers to designate that portion of the total energy of the food which is capable of conversion into the kinetic form in the body. In this sense it is equivalent to energy of food minus energy of excreta or to what is often called "fuel value."

The data of the foregoing pages enable us to compute the metabolizable energy of the rations in the several periods. Before doing so, however, a certain correction is necessary in the energy of the urine. For example, in Period I the animal lost 12.08 grams of body nitrogen, corresponding to a loss of 72.48 grams of protein. According to Rubner's results, the potential energy of the urine is increased by about 7.45 calories for each gram of urinary nitrogen coming from the oxidation of body protein. In this case, then, the urine contained approximately 12.08 × 7.45 = 90 calories of energy not derived from the potential energy of the food but from that of body tissue. It is plain, then, that the potential energy of the urine must be diminished by this amount before it is subtracted from the gross energy of the food in order to get the true metabolizable energy of the latter. The corresponding corrections for the several periods, computed in this way, are as follows:

TABLE 27.—*Energy of urine.*

Period.	Observed.	Gain of nitrogen.	Equivalent energy.	Corrected energy of urine.
	Calories.	*Grams.*	*Calories.*	*Calories.*
I	1,046.4	−12.08	−90.0	956.4
II	1,522.3	− 1.04	− 7.8	1,514.5
III	1,247.2	− 6.12	−45.6	1,201.6

Using these corrected values the metabolizable energy of the clover hay fed is computed in the following table:

TABLE 28.—*Metabolizable energy of clover hay.*

	Period I.		Period II.		Period III.	
	Feed.	Excreta.	Feed.	Excreta.	Feed.	Excreta.
	Calories.	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*
Hay	13,170.7		22,557.7		18,535.1	
Feces		5,403.3		9,132.0		7,666.1
Urine (corrected)		956.4		1,514.5		1,201.6
Methane		888.9		[a]1,221.0		1,053.0
Metabolizable		5,922.1		10,690.2		8,614.4
	13,170.7	13,170.7	22,557.7	22,557.7	18,535.1	18,535.1

[a] Period II*a* only.

The relation of the metabolizable energy to the amount of matter in the food may be expressed in terms of calories per gram of the total or of the digested organic matter. Computed in this way the results are as shown in the following table:

TABLE 29.—*Metabolizable energy per gram of organic matter.*

Period.	Organic matter of hay.		Metabolizable energy.		
	Total.	Digested.	Total.	Per gram of total organic matter.	Per gram of digestible organic matter.
	Grams.	*Grams.*	*Calories.*	*Calories.*	*Calories.*
I	2,730.3	1,712.0	5,922.1	2.169	3.460
II	4,668.0	2,939.0	10,690.2	2.290	3.637
III	3,856.0	2,407.6	8,614.4	2.234	3.578

The metabolizable energy of a feeding stuff may also be expressed as a percentage of the total or gross energy. Such a percentage is analogous to a digestion coefficient, so that if an average value for it were established for any particular kind of feeding stuff the amount of metabolizable energy in a given amount of it could be computed from its total energy by multiplication by this coefficient, just as the digestible dry matter or organic matter can be computed from the total amount present by the use of a digestion coefficient. The first half of the following table shows the percentage of the total energy which escaped in the several excreta or which was metabolized in the animal's body, while the second half of the table shows the same relations based upon the energy of the digested matter.

TABLE 30.—*Distribution of energy of clover hay.*

Energy.	Gross energy.				Energy of digested matter.			
	Period I.	Period II.	Period III.	Average.	Period I.	Period II.	Period III.	Average.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
In feces	41.03	40.49	41.31	40.96	....	....	....	....
In urine	7.25	6.72	6.48	6.81	12.30	11.28	11.05	11.54
In methane	6.75	5.41	5.68	5.95	11.44	9.09	9.69	10.07
Metabolizable	44.97	47.38	46.48	46.28	76.26	79.63	79.26	78.39
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

INFLUENCE OF TEMPERATURE ON HEAT PRODUCTION.

As stated in the introduction, one of the purposes of the experiment was to observe the effect of temperature upon the total metabolism, so far as this could be done within the limited range of the apparatus. Two series of respiration experiments were made, one at 19° C. and one at 13.5° C., these being designated as series *a* and series *b*, respectively. The results have already been given in the description of the experiment, but are brought together here for more convenient comparison.

TABLE 31.—*Heat production.*

Period.	Series *a*, at 19° C.				Series *b*, at 13.5° C.			
	Given off by radiation and conduction.	Given off as latent heat of water vapor.	Correction for water balance.	Total.	Given off by radiation and conduction.	Given off as latent heat of water vapor.	Correction for water balance.	Total.
	Calories.	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*
I	8,684.1	2,320.7	−93.9	10,910.9	9,994.4	1,702.5	+ 39.4	11,736.3
II	8,731.6	2,782.9	−79.7	11,434.9	9,100.3	1,973.5	+243.8	11,317.6
III	8,074.3	2,718.3	−69.1	10,723.6	8,803.0	2,049.5	+ 21.7	10,874.2

In Period I*b*, as shown in Table 17, the animal stood constantly for forty-eight hours, and as would be expected the heat production appears to be abnormally high. In the other cases the difference of 5.5° C. in temperature seems to have made but a slight difference in the total heat production.

But, while this is true as regards the total amount of heat produced, the difference in temperature made a striking difference in the channel of excretion by which the body rid itself of its heat. A much less proportion of it was removed as latent heat of water vapor and correspondingly more by radiation and conduction at the lower temperature, as is shown clearly in the following table, based on the figures for heat production just given. The correction for the water balance is taken as representing heat stored temporarily in the body.

TABLE 32.—*Percentage distribution of heat produced.*

Period.	Series *a*, at 19° C.			Series *b*, at 13.5° C.		
	Given off by radiation and conduction.	Given off as latent heat of water vapor.	Stored in body.	Given off by radiation and conduction.	Given off as latent heat of water vapor.	Stored in body.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
I	79.59	21.27	−0.86	85.16	14.51	0.33
II	76.36	24.34	−0.70	80.41	17.44	2.15
III	75.29	25.35	−0.64	80.95	18.85	0.20

The relative humidity of the air does not appear in this case to have been an important factor in bringing about the marked decrease in the evaporation of water at the lower temperature. The relative humidity of the ingoing and of the outcoming air, and also the average relative humidity of the four residual samples taken at the end of each subperiod, were as follows:

TABLE 33.—*Relative humidity.*

Period.	Ingoing air.	Outcoming air.	Residual samples.
	Per cent.	*Per cent.*	*Per cent.*
I*a*	2.3	28.2	27.2
II*a*	2.4	32.1	29.7
III*a*	2.2	30.6	29.7
I*b*	4.9	29.9	28.7
II*b*	4.7	33.8	34.7
III*b*	2.3	31.2	32.3

Apparently the difference in the method of excretion of the heat was a direct effect of the lower temperature.

NET AVAILABLE ENERGY.

Both our own observations and those of others, notably those of Zuntz and his associates, have shown that a considerable portion of the metabolizable energy of the food may be consumed in those mechanical and chemical processes incident to the digestion of the food and its conversion into forms fitted to nourish the body, or may otherwise be converted into the form of heat, and so not be directly available to make good the losses of potential energy from the body caused by the vital processes. The portion of the metabolizable energy remaining after subtracting the portion thus expended represents the net contribution which the food has made to the maintenance of the stock of potential energy in the body. This portion of the energy of the food is designated as net available energy. In other words, it is energy available for maintenance.

As explained in previous bulletins, the availability of the energy of a feeding stuff is determined by a comparison of the losses of energy by the animal in periods in which different amounts of the feed in question are consumed. In this experiment three different amounts of clover hay were fed to the animal, and consequently a comparison of the three periods should give us two results regarding availability in Series *a* and two in Series *b*.

The losses of protein and fat by the animal as tabulated on preceding pages do not take account of the amounts of matter and energy contained in the brushings, which are tabulated separately. It is clear, however, that these ought to be included in a computation of availability, since a portion of the energy of the food was expended in their production. Furthermore, since the metabolizable energy of the food has been corrected in Table 27, for the gain or loss of nitrogen by the animal, the figures for the gain or loss of engery should be similarily corrected by adding to the gain (i. e., subtracting from the loss) 7.45 calories for each gram of nitrogen lost by the animal. Indicating gain or loss by the mathematical signs + and −, the corrections and the corrected gains were as shown in the following table:

TABLE 34.—*Corrected gains.*

	Gain according to previous tables.	Correction for—		Corrected gain.
		Brushings.	Gain of protein.	
Computed from balance of nitrogen and carbon:	*Calories.*	*Calories.*	*Calories.*	*Calories.*
Period Ia	−5,243.0	+41.3	+90.0	−5,111.7
Period IIa	−1,339.0	+41.3	+ 7.8	−1,289.0
Period IIIa	−2,714.5	+41.3	+45.6	−2,627.6
Period Ib	−5,374.1	+41.3	+90.0	−5,242.8
Period IIb	−1,086.3	+41.3	+ 7.8	−1,037.2
Period IIIb	−2,570.1	+41.3	+45.6	−2,483.2
Computed from balance of energy:				
Period Ia	−5,140.1	+41.3	+90.0	−5,008.8
Period IIa	− 793.8	+41.3	+ 7.8	− 744.7
Period IIIa	−2,164.1	+41.3	+45.6	−2,077.2
Period Ib	−5,925.5	+41.3	+90.0	−5,794.2
Period IIb	− 676.5	+41.3	+ 7.8	− 627.4
Period IIIb	−2,378.9	+41.3	+45.6	−2,292.0

As already noted, there was no marked difference between Series *a* and Series *b* as regards heat production or loss except in Period Ib. In this period for some reason the animal refused to lie down at all. It is presumably in consequence of this fact that the observed heat production was considerably higher than in the corresponding

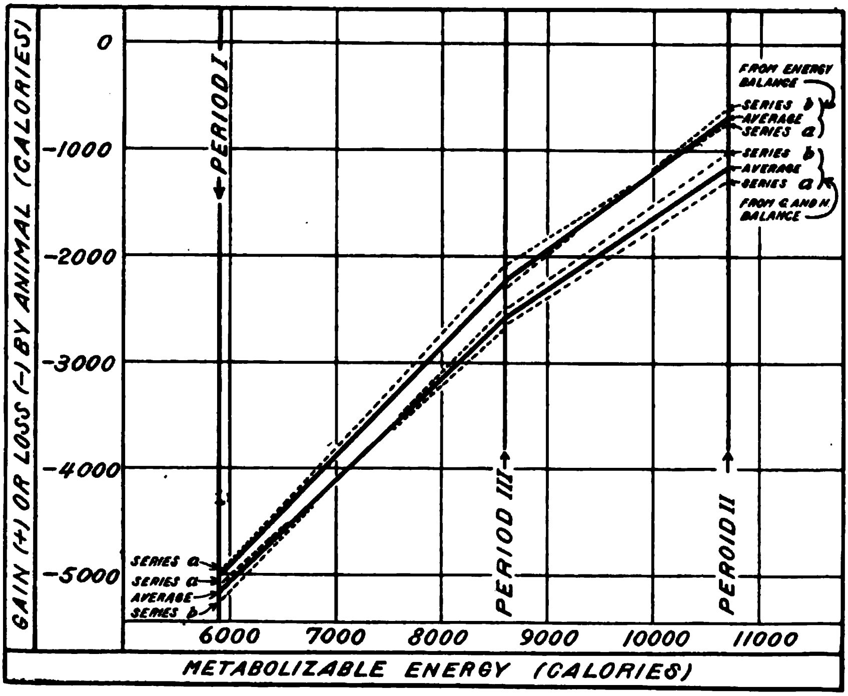

DIAGRAM 2.—Availability of energy.

Period I*a*, although this is not true of the heat production as computed from the balance of nitrogen and carbon. If we arbitrarily reject Period I*b* as having been under abnormal conditions and plat the data of the remaining experiments as in previous bulletins, we have the results for the two series separately and for their average, which are shown in Diagram 2. While the losses as computed from the carbon and nitrogen balance are greater than those deduced from the energy balance, the average results of Series *a* and Series *b* are quite closely parallel.

If, on the other hand, again omitting the results for energy of Period I*b*, we average for each series separately the results as computed from the carbon and nitrogen balance and those computed from the energy, we have the results shown in Diagram 3, which again expresses the fact, already pointed out, that a very slight difference was shown between the results of Series *a* and those of Series *b*.

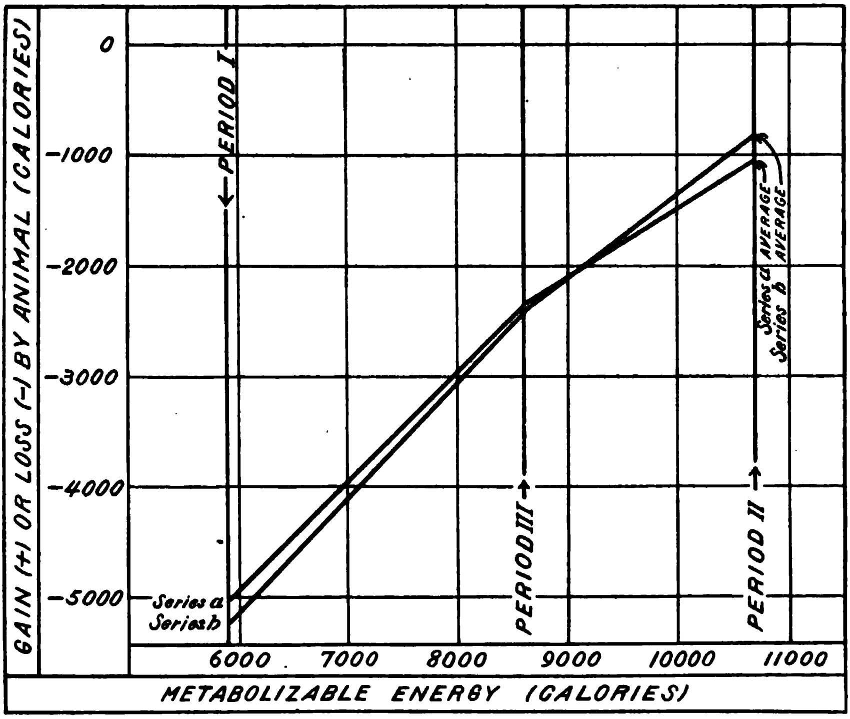

DIAGRAM 3.—Average results of carbon and nitrogen and energy balances.

As previously stated, the results of the calorimeter experiments I*b* and II*b* were not as satisfactory as the others. In both cases the balance of energy was obtained for twenty-four hours only, owing to various disarrangements of the apparatus, and in subperiod

4 of Period II*b* the methane determination is lacking. On the whole, therefore, we incline to attach considerably more value to the results of Series *a* than to those of Series *b*.

CORRECTIONS FOR STANDING AND LYING.

The average number of hours per day during which the animal lay down in the several periods was, as shown in Tables 17 and 18:

Period I*a*, 3 hours, 12 minutes.
Period II*a*, 7 hours, 47 minutes.
Period III*a*, 9 hours, 8 minutes.

Period I*b*, ———.
Period II*b*, 2 hours, 17 minutes.
Period III*b*, 6 hours, 38 minutes.

In view of the very marked influence of standing as compared with lying upon the metabolism of the animal, as shown in all our experiments, it is evident that the results of the several periods are not strictly comparable. Unfortunately, the data available for computing a correction are not fully sufficient, because, although the variations in the rate at which heat was given off by radiation and conduction are shown by the records of the experiment, as summarized in Tables 17 and 18, the apparatus does not permit similar determinations of the rate at which heat was carried off as latent heat of water vapor.

The best approximation which is available appears to be that outlined in Bulletin 51 of this Bureau, page 38. This consists in assuming, on the one hand, that the rate of elimination of water vapor varied at the same rate as that of the radiation of heat, and, on the other hand, that it was unaffected by the position of the animal. It would seem that these two hypotheses may be fairly regarded as representing the extremes of probable variation, and if, as appears to be the case, the results when corrected on these two hypotheses are substantially concordant, we shall be inclined to regard them as probably correct.

In place of computing the metabolism for the entire twenty-four hours either standing or lying, as was done in Bulletin 51, we have preferred in this case to compute the results, on the two hypotheses above stated, to a uniform period of seven hours passed lying down. The method of computation may be illustrated by the results of Period I*a*. In this period, as appears from Table 19, the average rate at which heat was given off by radiation and conduction and brought out of the calorimeter in the water current was:

Standing, 6.2700 calories per minute.
Lying, 4.4747 calories per minute.

If the animal had lain down for seven hours out of the twenty-four, the total heat given off through these channels would have been:

Standing 17 hours, 6.2700 calories × 1,020=6,395.4 calories.
Lying 7 hours, 4.4747 calories × 420=1,879.4 calories.

Total 24 hours .... 8,274.8 calories.

The heat actually carried off as latent heat of water vapor in this period was 2,320.7 calories, and constituted 21.09 per cent of the total heat emission. Upon the first hypothesis, then, the total heat emission would have been:

$$\frac{8,274.8}{0.7891}=10,486.4 \text{ calories.}$$

Upon the second hypothesis, that of unchanged elimination of water vapor, the total heat emission would have been:

$$8,274.8+2,320.7=10,595.5 \text{ calories.}$$

To find the actual heat production, the above figures must be corrected as in Table 21 for the results of the water balance, the correction in this period being −93.9 calories. Accordingly the heat production computed for Period I*a* on the assumption that the animal lay down for seven hours is:

On the first hypothesis, 10,392.5 calories.
On the second hypothesis, 10,501.6 calories.

Identical computations for the other periods give the results stated in the following table. In the case of Period I*b* of course no data are available for such a computation.

TABLE 35.—*Computed heat production—Seven hours lying.*

Period.	On the first hypothesis.	On the second hypothesis.
	Calories.	*Calories.*
I*a*	10,392.0	10,501.6
II*a*	11,580.9	11,545.5
III*a*	11,083.2	10,992.2
II*b*	10,983.6	11,043.2
III*b*	10,826.7	10,835.1

The corresponding (negative) gains by the animal—computed, of course, from the energy results, since we have no corresponding data for the carbon and nitrogen balance—would be as shown in the following table, in which the corrections for the brushings and for the gains of protein have been included in the same manner as in Table 34:

TABLE 36.—*Computed gains—Seven hours lying.*

Period.	On the first hypothesis.	On the second hypothesis.
	Calories.	*Calories.*
I*a*	−4,489.9	−4,509.5
II*a*	−890.7	865.3
III*a*	2,436.8	−2,345.8
II*b*	−293.4	−353.0
III*b*	−2,244.1	2,252.5

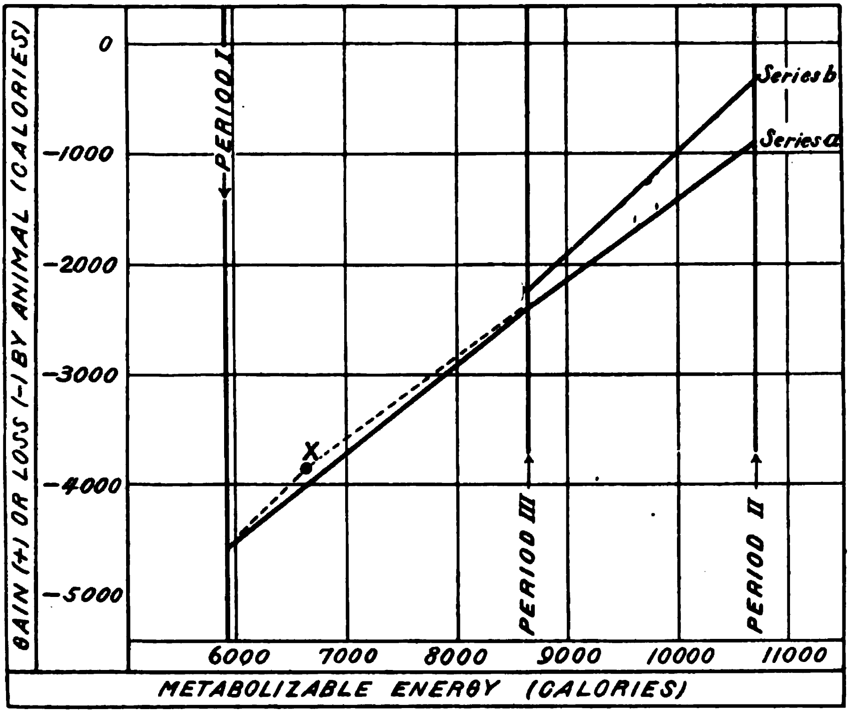

DIAGRAM 4.—Average results from energy balances computed to 17 hours' standing.

The averages of these results compared with the amounts of metabolizable energy supplied in the feed are expressed graphically in Diagram 4 and are computed numerically in the following table, which includes also the amounts of total and of digested organic matter consumed by the animal in each period.

TABLE 37.—*Availability of metabolizable energy.*

Series and period.	Organic matter.		Metabolizable energy.	On first hypothesis.		On second hypothesis.		Average.	
	Total.	Digestible.		Gain.	Availability.	Gain.	Availability.	Gain.	Availability.
	Grams.	*Grams.*	*Calories.*	*Calories.*	*Per ct.*	*Calories.*	*Per ct.*	*Calories.*	*Per ct.*
Series *a*:									
Period III.....	3,856.0	2,407.6	8,614.4	−2,436.8	....	−2,345.8	....	−2,391.3	....
Period I.......	2,730.3	1,712.0	5,922.1	−4,489.9	....	−4,599.5	....	−4,544.7	....
Difference...	1,125.7	695.6	2,692.3	2,053.1	76.26	2,253.7	83.71	2,153.4	79.99
Period II......	4,668.0	2,939.0	10,690.2	− 890.7	....	− 865.3	....	− 878.0	....
Period III.....	3,856.0	2,407.6	8,614.4	−2,436.8	....	−2,345.8	....	−2,391.3	....
Difference...	812.0	531.4	2,075.8	1,546.1	74.48	1,480.5	71.32	1,513.3	72.90
Series *b*:									
Period II......	4,668.0	2,939.0	10,690.2	− 293.4	....	− 353.0	....	− 323.2	....
Period III.....	3,856.0	2,407.6	8,614.4	−2,244.1	....	−2,252.5	....	−2,248.3	....
Difference...	812.0	531.4	2,075.8	1,950.7	93.96	1,899.5	91.51	1,925.1	92.74

It must be admitted that the results as they stand do not appear especially satisfactory. In particular, the correction to a uniform period of lying has the effect of destroying the approximate correspondence between the results at different temperatures which was indicated by Diagrams 2 and 3. The corrected results show apparently a considerably smaller loss by the animal in Period II*b*, at the lower temperature, than in Period II*a*. This result seems unlikely, and, as already noted, both Periods I*b* and II*b* were not altogether satisfactory.

Strictly speaking, the results should be corrected also for differences in the weight of the animal. Our apparatus does not permit taking the weight of the animal during the respiration period, but the weight is taken immediately before entering and immediately after leaving the calorimeter. If we may assume that the average of the last two weights before the respiration period and the first two succeeding it represent approximately the average weight of the animal during the trial, we have the following as the live weights in the different periods:

Live weights of animal during respiration periods.

Period.	Series *a*.	Series *b*.
	Kilograms.	*Kilograms.*
I..	571.1	553.7
II...	586.7	576.0
III..	580.1	565.8

It must be remembered, however, that these variations in weight were doubtless due to a considerable extent to variations in the amount of material contained in the digestive tract on the different rations. We can hardly suppose that the actual radiating surface of the body was materially different in the different periods, although, on the other hand, the metabolism incident to the maintenance of the standing position would naturally be greater the greater the weight of the animal, as was indeed found to be the case. Any probable corrections for the influence of the live weight, however, are so small as to be insignificant as compared with other sources of error and are therefore not taken account of in these computations.

HEAT REQUIREMENT OF THE ANIMAL.

If we confine our attention to the results of Series *a* as being on the whole decidedly more satisfactory than those of Series *b*, we have apparently a greater average availability between Periods I and III than between Periods III and II. A similar result was noted in Bulletin 51 in the results computed for the lying position. This difference was there interpreted (page 57) as indicating an indirect utilization by the animal of the heat resulting from the digestion and assimilation of the light ration. This view assumes that at a given temperature a certain minimum amount of heat is required by the animal organism to maintain its temperature, and that if this amount of heat is not produced by the ordinary activity of the internal organs and the muscles it will be supplied by a direct combustion of food or tissue for the purpose of heat production. In the case observed in Bulletin 51 it was believed that when the animal was lying down the necessary production of heat aside from that resulting from the ingestion of food was insufficient to supply the demands of the animal. On the heavier ration a part only of the heat resulting from the work of digestion and assimilation was required, in addition to that produced by the internal work, to supply the demand for heat. As the amount of food was decreased, however, a point was reached at which all the heat produced by digestion and assimilation was required for this purpose, while with a still smaller amount of food a portion of the animal tissue had to be metabolized to supply the necessary heat. At or below this point, then, the entire metabolizable energy of the food was of use to the animal and the apparent availability became 100 per cent, represented graphically on Diagram III of Bulletin 51 by the dotted lines, making an angle of 45 degrees with the coordinates. It is of some interest to apply the same interpretation to this experiment and to compare the results obtained with those found in the previous experiment.

In the experiments of 1901–2 the average live weight of the animal in Periods A and B, the ones to be compared, was 401.8 kilograms. The computed heat production, lying, in Period A was:

On the first hypothesis	7,920 calories.
On the second hypothesis	8,250 calories.
Average	8,085 calories.

This average amount we may regard as representing the minimum of heat required by the animal.

In the present experiments the average live weight for Periods I and III was 574.3 kilograms. The heat production in Period I*a*, computed to seven hours lying, was, as previously shown:

On the first hypothesis	10,392 calories.
On the second hypothesis	10,502 calories.
Average	10,447 calories.

which we may regard as being the minimum required for the older and larger animal.

It seems to be fairly well established that the requirement of the animal body for heat is substantially proportional to its surface, or, what is approximately the same thing, to the two-thirds power of its volume or weight. On this hypothesis we can compute from the observed results the probable minimum requirement of an animal weighing 500 kilograms as follows:

Experiment of 1901–2.

On the first hypothesis, $7{,}920 \text{ calories} \times \left(\frac{500}{401.8}\right)^{\frac{2}{3}} = 9{,}163$ calories.

On the second hypothesis, $8{,}250 \text{ calories} \times \left(\frac{500}{401.8}\right)^{\frac{2}{3}} = 9{,}545$ calories.

Average .... 9,354 calories.

Experiment of 1903–4.

On the first hypothesis, $10{,}395 \text{ calories} \times \left(\frac{500}{574.3}\right)^{\frac{2}{3}} = 9{,}478$ calories.

On the second hypothesis, $10{,}503 \text{ calories} \times \left(\frac{500}{574.3}\right)^{\frac{2}{3}} = 9{,}576$ calories.

Average .... 9,527 calories.

The close agreement of these figures seems to support strongly the view advanced above, namely, that on the lighter ration of Period I the animal was consuming its own tissue for heat production and that up to a point between this and the ration of Period III the food would show an apparent availability of 100 per cent. In other words, we conclude that the availability would be represented approximately by the dotted line in Diagram 4. The point at which the relation changes is indicated on the diagram at X, and could, of course, be computed numerically by the methods of analytical geometry.

If this interpretation of the results is correct, the loss of tissue in Period I*b*, at 13.5° C., should be greater than in Period I*a*, at 19° C., and, as a matter of fact, that appears to be the tendency, although the results are uncertain. On the same hypothesis the losses in Periods II and III should be the same at both temperatures. Such an equality was observed in Period III, but not in Period II. In the latter, as already noted, the loss, computed for seven hours lying, was less at the lower than at the higher temperature.

MAINTENANCE REQUIREMENT OF THE ANIMAL.

Another method of comparing the results of the two experiments is to compute the maintenance requirement of the animal for a uniform weight of, say, 500 kilograms. The maintenance requirement may be defined as the amount of food which supplies sufficient available energy to make good the losses incident to the vital activities of the animal. Owing to the varying degree of availability of different foods, the total weight of food—or the total metabolizable energy—required will vary with the feeding stuff used. The maintenance requirement, therefore, is most logically expressed in terms of available energy, and its amount will be found graphically by producing the line representing the availability of the food until it intersects the vertical axis. The distance from the origin to this point of intersection will represent the maintenance requirement in terms of available energy, or, in other words, it will be the theoretical fasting metabolism of the animal at the given temperature. Performing the same operation arithmetically, we have, on the basis of the average results of Period II*a*, the following:

$$(10{,}690 \text{ calories} \times 0.729) + 878 \text{ calories} = 8{,}671 \text{ calories, maintenance requirement.}$$

For the experiments of 1901–2 the computation is not so simple, because the rations employed contained in each case 400 grams of linseed meal, a material whose net available energy has not yet been determined. Its utilizable energy (production value), however, compared with that of maize, as computed by the use of Kellner's factors[a], is:

100 pounds linseed meal=78,929 calories.
100 pounds maize=88,847 calories.

If we assume that the net available energy of the two materials is proportional to their utilizable energy, we may compute the net available energy of linseed meal per kilogram of dry matter from that of maize, as given in the first table on page 40 of Bulletin 74 of this Bureau, as follows:

$$2.679 \text{ calories} \times \frac{78{,}929}{88{,}847} = 2.381 \text{ calories per gram of dry matter.}$$

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[a] Pennsylvania Experiment Station Bulletin 71 (revised), page 16.

Upon this assumption the maintenance requirement of the animal in Periods A and B of the experiment of 1901–2 would be as follows:

TABLE 38.—*Computation of maintenance requirement according to experiment of 1901–2.*

	Dry matter eaten.	Net available energy per gram.	Net available energy of ration.
Period A:	*Grams.*	*Calories.*	*Calories.*
Hay	2,879.5	1.268	3,652
Linseed meal	357.8	2.381	852
Loss from body			2,578
Maintenance			7,082
Period B:			
Hay	4,018.0	1.268	5,097
Linseed meal	354.7	2.381	845
Loss from body			791
Maintenance			6,733
Average maintenance			6,908

The time spent standing in the experiment of 1901–2 was, on the average of Periods A and B, fifteen hours. This does not differ sufficiently from the seventeen hours to which the results of 1903–4 have been computed to render a correction necessary for the purposes of the present approximate comparison. The reduction of the above figures to a live weight of 500 kilograms gives the following results:

Experiment of 1903–4, 8,671 calories $\times\left(\frac{500}{583.4}\right)^{\frac{2}{3}}$ = 7,824 calories.

Experiment of 1901–2, 6,908 calories $\times\left(\frac{500}{401.8}\right)^{\frac{2}{3}}$ = 7,992 calories.

We find, then, that if we assume that the results obtained by comparing Periods II and III represent the true availability of the clover hay, and that the divergent results obtained by the comparison of Periods III and I can be explained in the manner just detailed, we obtain results which are closely concordant with those of earlier experiments both as to the minimum requirements of the animal for heat and as to the amount of available energy required for maintenance. In spite, therefore, of the somewhat unsatisfactory nature of the experiment there seems good reason to believe that the availability of the metabolizable energy of the clover hay was in the neighborhood of 73 per cent, and that the much lower figure obtained in the previous year's experiment was erroneous. The latter conclusion is further strengthened by computing in the same way from the results of that experiment the maintenance requirement of the animal in terms of available energy. A computation similar to that used above gives as a result, for the live weight of 500 kilograms, 5,907 calories. This result is so much lower than those computed from the other two experiments as to be almost certainly erroneous and indicates that for some reason the loss by the animal in Period II of the experiment in 1903 was overestimated.

DISTRIBUTION OF ENERGY.

Using the above corrected figure for the availability of clover hay, we may derive the following corrected figures for the percentage distribution of the energy of several feeds which were tabulated on pages 44 to 46 of Bulletin 74:

TABLE 39.—*Percentage distribution of total energy.*

	Timothy hay.	Clover hay.	Meadow hay.	Maize meal.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
In feces	48.90	40.96	40.96	9.18
In urine	3.06	6.81	5.71	3.83
In methane	3.79	5.95	6.77	9.31
Expended in digestion and assimilation	16.41	12.49	27.28	17.23
Expended in tissue formation	13.10	33.79		19.06
Stored as gain by animal	14.74		19.28	41.39
	100.00	100.00	100.00	100.00
Available for maintenance	27.84	33.79	....	60.45

TABLE 40.—*Percentage distribution of energy of digested matter.*

	Timothy hay.	Clover hay.	Meadow hay.	Maize meal.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
In urine	6.00	11.53	9.66	4.22
In methane	7.42	10.08	11.57	10.25
In digestion and assimilation	32.10	21.15	46.08	18.97
In tissue formation	25.64	57.24		20.99
Stored as gain	28.84		32.69	45.57
	100.00	100.00	100.00	100.00
Available for maintenance	54.49	27.61	....	66.55

The same results may also be computed in calories per unit of dry matter, using the percentages of the above tables as coefficients. The total or gross energy of the materials, taking in case of timothy hay, clover hay, and maize meal the average of the two general samples, was as follows:

TABLE 41.—*Total or gross energy of materials.*

	Per kilogram dry matter.	Per kilogram digested organic matter.
	Calories.	*Calories.*
Timothy hay	4,554	[a] 4,382
Clover hay	4,492	[b] 4,476
Maize meal	4,431	[c] 4,327
German meadow hay	4,413	4,437

[a] Preliminary period, steer No. 1. [b] Average of Periods I and II. [c] Average of Periods III and IV.

On this basis have been computed the figures of the tables following, showing the total energy per kilogram of dry matter and its distribution in accordance with the percentage figures already given.

TABLE 42.—*Energy per kilogram of total dry matter.*

	Timothy hay.	Clover hay.	Meadow hay.	Maize meal.
	Calories.	*Calories.*	*Calories.*	*Calories.*
Lost in feces	2,227	1,840	1,807	407
Lost in urine	139	306	252	170
Lost in methane	173	267	299	413
Expended in digestion and assimilation	747	561	1,204	763
Expended in tissue formation	597	1,518		844
Stored as gain	671		851	1,834
Total	4,554	4,492	4,413	4,431
Available for maintenance	1,268	1,518	....	2,679

TABLE 43.—*Energy per kilogram of digestible organic matter.*

	Timothy hay.	Clover hay.	Meadow hay.	Maize meal.
	Calories.	*Calories.*	*Calories.*	*Calories.*
Lost in urine	262	516	429	183
Lost in methane	325	451	513	443
Expended in digestion and assimilation	1,407	947	2,045	821
Expended in tissue formation	1,124	2,562		908
Stored as gain	1,264		1,450	1,972
Total	4,382	4,476	1,437	4,327
Available for maintenance	2,388	2,562	....	2,880

Taking the figures for timothy hay as unity, the relative values of these four feeding stuffs are as follows:

TABLE 44.—*Relative values.*

Feed.	Per kilogram total dry matter.		Per kilogram digestible organic matter.	
	For maintenance.	For fattening.	For maintenance.	For fattening.
Timothy hay	1.00	1.00	1.00	1.00
Clover hay	1.20	....	1.07	....
Meadow hay	....	1.27	....	1.15
Maize meal	2.11	2.73	1.21	1.56

APPENDIX.

TABLE I.—*Live weight, water drunk, and excreta of animal fed on clover hay.*

[For 24 hours ended at 6. p. m. on date given.]

Period and date.	Live weight.	Water drunk.	Feces.	Urine.[a]
Period I.				
Jan., 1904.	*Kilos.*	*Kilos.*	*Grams.*	*Grams.*
2	619.5	0.0		
3	592.4	28.6		
4	597.0	8.0		
5	584.2	22.2		
6	586.1	0.0		
7	569.8	27.3		
8	577.8	21.0		
9	582.7	0.0		
10	570.8	0.0		
11	558.6	34.7		
12	[b] 580.8	0.0		
	[c] 577.6			
13		11.33	3,590	4,034
14	[d] 565.3	.76	5,940	3,125
15	560.5	23.9	5,425	4,803
16	565.1	24.6	5,335	11,635
17	571.2	8.5	6,042	10,002
18	562.6	9.5	5,994	10,252
19	[b] 560.7	0.0		
	[c] 557.2		5,746	6,861
20		3.564	6,172	3,724
21	[d] 550.7	11.895	6,609	2,705
22	546.2	25.8	4,075	4,650
Total			54,937	62,127
Spilled in calorimeter Jan. 14			109.1	95.85
Dung from duct Jan. 14			18.0	
Spilled in stall Jan. 16			1.2	230.96
Spilled in calorimeter Jan. 21			25.1	39.35
Spilled in stall Jan. 22			36.6	
Transition period:				
Jan. 23	552.0	19.0		
24	560.4	19.8		
25	571.0	16.4		
26	576.8	18.8		
27	582.8	15.1		
28	584.8	25.6		
29	594.9	14.0		
Period II.				
Jan., 1904.				
30	597.8	13.0		
31	597.4	40.8		
Feb., 1904.				
1	596.2	25.2		
2	596.4	5.4		
3	584.6	29.1		
4	594.9	19.5		
5	594.8	6.2		
6	584.2	22.8		
7	589.3	13.9		
8	585.0	11.3		
9	[b] 597.2			
	[c] 584.5	15.4		
10		11.952	12,165	5,446
11	[d] 587.1	17.470	10,807	5,825
12	578.1	12.1	8,725	7,468
Period II—Con.				
Feb., 1904—Con.	*Kilos.*	*Kilos.*	*Grams.*	*Grams.*
13	567.6	22.1	10,709	7.798
14	565.1	21.8	9,324	5,977
15	573.4	14.0	10,645	8,278
16	[b] 577.6	0.0		
	[c] 572.4		8,815	7.753
17		25.67	9,711	5.484
18	[d] 579.3	14.46	8,806	5.305
19	574.8	15.60	8,100	6.452
Total			97.807	65,796
Spilled in calorimeter Feb. 11			142.4	
Spilled in stall Feb. 13			51.6	
Spilled in calorimeter Feb. 18			56.2	
Spilled in stall Feb. 19			4.7	
Transition period:				
Feb. 21	571.2	27.2		
22	581.1	20.8		
23	583.5	20.1		
24	586.3	16.9		
25	586.1	15.7		
26	587.2	22.3		
Period III.				
Feb., 1904.				
27	590.5	17.2		
28	585.7	12.9		
29	579.7	15.0		
Mar., 1904.				
1	579.0	18.5		
2	581.0	14.9		
3	579.2	11.4		
4	575.1	17.0		
5	577.8	2.3		
6	567.8	23.7		
7	578.6	2.0		
8	[b] 572.0	23.0		
	[a] 590.8			
9		5.205	7,306	4,770
10	[d] 583.6	16.020	6,504	4,697
11	573.8	1.4	8,082	5,287
12	560.2	22.2	7,768	4,735
13	569.8	7.8	7,810	4,452
14	564.2	16.1	7,710	[e][3,097]
15	567.4		6,392	4,707
16		18.100	8,449	4,657
17	[d] 569.2	11.200	7,385	4,735
18	562.2	14.4	8,287	5,038
Total			75,693	46.175
Spilled in calorimeter Mar. 10			37.0	
Spilled in stall Mar. 14				441
Spilled in calorimeter Mar. 17			20.6	

[a] Including wash water.
[b] Taken at 7.30 a. m.
[c] Taken at 1 p. m.
[d] Taken at 6 p. m.
[e] Small loss of urine.

TABLE II.—*Composition of dry matter of feces.*

Constituents and energy.	Period I.	Period II.	Period III.	Constituents and energy.	Period I.	Period II.	Period III.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
Ash	10.03	10.88	10.99	Total nitrogen	2.28	2.24	2.24
Protein (N × 6.25)	14.25	14.06	14.01	Proteid nitrogen	2.06	2.06	1.97
Crude fiber	32.90	31.95	33.86	Carbon	48.29	48.03	47.94
Nitrogen-free extract	39.56	39.91	38.21	Hydrogen	6.07	6.15	6.23
Ether extract	3.26	3.20	2.93		*Calories per gram.*	*Calories per gram.*	*Calories per gram.*
	100.00	100.00	100.00	Heat of combustion	4,770.4	4,707.0	4,711.4

TABLE III.—*Digestibility of rations.*

	Dry matter.	Ash.	Organic matter.	Proteids.	Non-proteids.	Crude fiber.	Nitrogen-free extract.	Ether extract.	Nitrogen.	Carbon.	Energy.
Period I.	*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Grms.*	*Cals.*
Hay	2,933.3	203.0	2,730.3	355.2	39.6	834.8	1,403.0	97.7	65.2	1,366.1	13,170.7
Feces	1,131.9	113.6	1,018.3	161.4	......	372.6	448.2	36.9	25.9	547.0	5,403.3
Digested	1,801.4	89.4	1,712.0	193.8	39.6	462.2	954.8	60.8	39.3	819.1	7,767.4
Coefficient, p.ct.	61.41	44.04	62.70	54.56	100.00	55.37	68.05	62.24	60.36	59.96	58.97
Period II.											
Hay	5,025.3	357.3	4,668.0	594.0	81.9	1,408.1	2,411.1	172.9	112.5	2,323.7	22,557.7
Feces	1,940.1	211.1	1,729.0	272.8	......	619.9	774.2	62.1	43.5	931.8	9,132.0
Digested	3,085.2	146.2	2,939.0	321.2	81.9	788.2	1,636.9	110.8	69.0	1,391.9	13,425.7
Coefficient, p.ct.	61.39	40.92	62.96	54.08	100.00	55.97	67.90	64.08	61.37	59.89	59.51
Period III.											
Hay	4,139.1	283.1	3,856.0	490.1	60.0	1,193.0	1,974.2	138.7	91.2	1,911.0	18,535.1
Feces	1,627.2	178.8	1,448.4	228.0	......	551.0	621.7	47.7	36.4	980.0	7,666.1
Digested	2,511.9	104.3	2,407.6	262.1	60.0	642.0	1,352.5	91.0	54.8	1,131.0	10,869.0
Coefficient, p.ct.	60.68	36.83	62.43	53.48	100.00	53.81	68.51	65.62	60.08	59.18	58.64

TABLE IV.—*Results on urine (inclusive of wash water).*

Period.	Weight.	Average specific gravity.	Total nitrogen.		Total carbon.		Energy.	
							Per kilogram.	Total.
Period I.	*Grams.*		*Per ct.*	*Grams.*	*Per ct.*	*Grams.*	*Calories.*	*Calories.*
Total collected	62,157	....	0.813	507.53	1.797	1,121.48	....	....
Daily average (10 days)	6,215.7	1.0379	....	50.75	....	112.15	167.6	1,046.40
Period II.								
Total collected	65,796	....	1.050	690.5	2.566	1,687.6	....	....
Daily average (10 days)	6,579.6	1.0411	....	69.05	....	168.76	231.4	1,522.25
Period III.								
Total collected	46,616	....	1.299	605.5	3.040	1,418.0	....	....
Daily average (10 days)	4,661.6	1.0432	....	60.55	....	141.80	267.5	1,247.16

TABLE V.—*Residual air.*

Period.	Aspirator reading.	Barometer.[a]	Temperature.	Weight.		Corresponding volume at 0° and 760 mm.		Total volume of sample reduced.		Volume of moist air in chamber reduced.	Total in chamber.	
				Water.	Carbon dioxid.	Water.	Carbon dioxid.	Dry.	As sampled.		Water.	Carbon dioxid.
Period Ia.	*Liters*	*Mm.*	*°C.*	*Gms.*	*Gms.*	*Liters*	*Liters*	*Liters*	*Liters*	*Liters*	*Gms.*	*Gms.*
At end of preliminary run...	25	713.44	15.6	0.1104	0.1064	0.14	0.05	22.24	22.38	10,753	53.04	51.12
At end of subperiod 1........	25	710.29	19.0	.1003	.1066	.12	.05	21.89	22.01	10,759	49.03	52.11
At end of subperiod 2........	25	701.80	20.2	.1088	.1020	.14	.05	21.55	21.69	10,646	53.40	50.07
At end of subperiod 3........	25	701.56	19.6	.1034	.0999	.13	.05	21.58	21.71	10,636	50.66	48.94
At end of subperiod 4........	25	705.37	19.1	.1041	.1122	.13	.06	21.75	21.88	10,687	50.84	54.80
Period IIa.												
At end of preliminary run...	25	723.33	17.0	.1129	.1211	.14	.06	22.46	22.60	10,917	54.54	58.50
At end of subperiod 1........	25	724.72	17.6	.1218	.1103	.15	.06	22.46	22.61	10,941	58.94	53.37
At end of subperiod 2........	25	724.17	18.2	.1169	.1198	.15	.06	22.39	22.54	10,944	56.76	58.17
At end of subperiod 3........	25	723.97	18.4	.1156	.1096	.14	.06	22.37	22.51	10,945	56.21	53.29
At end of subperiod 4........	25	720.98	19.2	.1159	.1142	.14	.06	22.22	22.36	10,911	56.55	55.72
Period IIIa.												
At end of preliminary run...	25	706.43	18.8	.1093	.1046	.14	.05	21.79	21.93	10,693	53.30	51.00
At end of subperiod 1........	25	710.71	16.8	.1114	.1010	.14	.05	22.07	22.21	10,726	53.80	48.78
At end of subperiod 2........	25	713.05	17.3	.1169	.1111	.14	.06	22.12	22.26	10,766	56.54	53.73
At end of subperiod 3........	25	717.18	17.2	.1189	.1010	.15	.05	22.27	22.42	10,825	57.41	48.76
At end of subperiod 4........	25	712.37	18.9	.1173	.1090	.15	.05	21.97	22.12	10,778	57.16	53.11
Period Ib.												
At end of preliminary run...	25	731.04	13.2	.0832	.1106	.10	.06	23.00	23.10	11,254	40.53	53.88
At end of subperiod 1........	25	724.46	16.0	.0657	.1066	.08	.05	22.56	22.64	11,198	32.50	52.73
At end of subperiod 2........	25	719.80	15.6	.0900	.1087	.11	.05	22.45	22.56	11,068	44.16	53.33
At end of subperiod 3........	25	717.81	14.6	.0867	.1117	.11	.06	22.47	22.58	11,028	42.34	54.55
At end of subperiod 4........	25	713.40	16.0	.0856	.1088	.11	.05	22.22	22.33	10,979	42.09	53.49
Period IIb.												
At end of preliminary run...	25	720.25	14.1	.0715	.1031	.09	.05	22.58	22.67	11,068	34.91	50.34
At end of subperiod 1........	25	720.49	18.0	.1165	.1121	.14	.06	22.29	22.43	10,959	56.92	54.77
At end of subperiod 2........	25	724.84	15.6	.0921	.1152	.11	.06	22.61	22.72	11,143	45.17	56.50
At end of subperiod 3........	25	725.20	16.2	.0961	.1171	.12	.06	22.58	22.70	11,142	47.17	57.48
At end of subperiod 4........	25	722.80	16.8	.0933	.1130	.12	.06	22.46	22.58	11,128	45.98	55.69
Period IIIb.												
At end of preliminary run...	25	712.67	15.7	.0830	.1043	.10	.05	22.22	22.32	10,954	40.73	51.19
At end of subperiod 1........	25	715.66	19.1	.0771	.0980	.10	.05	22.05	22.15	11,051	38.46	48.90
At end of subperiod 2........	25	721.80	16.6	.0879	.1047	.11	.05	22.43	22.54	11,084	43.22	51.49
At end of subperiod 3........	25	726.14	15.6	.1054	.1065	.13	.05	22.65	22.78	11,143	51.56	52.10
At end of subperiod 4........	25	719.79	17.5	.0981	.1156	.12	.06	22.31	22.43	11,077	48.45	57.09

[a] Corrected for tension of aqueous vapor. The air in the aspirator is assumed to be saturated.

TABLE VI.—*Ventilation.*

Period.	Volume at meter pump.	Average barometer.	Average tension of aqueous vapor.	Average temperature.	Reduced volume at meter pump, dry.	Sample of residual air.	Methane produced.	Volume of entering air, dry.
Period Ia.	*Liters.*	*Mm.*	*Mm.*	° *C.*	*Liters.*	*Liters.*	*Liters.*	*Liters.*
Subperiod 1......	454,412	726.6	1.66	16.8	408,344.4	21.89	48.61	408,317.6
Subperiod 2......	462,239	722.0	1.20	18.0	411,279.9	21.55	43.44	411,258.0
Subperiod 3......	463,428	718.8	1.09	18.0	410,587.3	21.58	50.78	410,588.1
Subperiod 4......	463,923	719.9	1.13	18.2	411,347.4	21.75	51.26	411,317.9
Period IIa.								
Subperiod 1......	471,508	739.0	1.75	15.3	433,076.6	22.46	58.79	433,040.3
Subperiod 2......	488,990	740.9	1.50	16.3	448,937.8	22.39	78.03	448,882.2
Subperiod 3......	488,247	739.9	1.48	15.5	448.887.4	22.37	71.99	448,837.7
Subperiod 4......	487,949	739.0	1.60	17.8	444,520.9	22.22	47.60	444,495.6
Period IIIa.								
Subperiod 1......	488,147	724.3	1.69	16.6	437,473.2	22.07	52.46	437,442.8
Subperiod 2......	493,993	727.3	2.37	16.6	444,206.9	22.12	63.77	444,165.2
Subperiod 3......	495,677	730.6	2.04	15.3	450,045.0	22.27	46.95	450,020.3
Subperiod 4......	498,936	731.8	1.68	15.5	453,543.0	21.97	51.23	453,513.8
Period Ib.								
Subperiod 1......	453,669	740.4	1.31	12.4	422,112.0	22.56	47.47	422,087.0
Subperiod 2......	459,415	735.4	1.02	14.0	422,288.6	22.45	43.50	422.267.6
Subperiod 3......	453,719	731.7	1.10	14.3	414,500.4	22.47	48.18	414,474.7
Subperiod 4......	454,164	728.4	1.00	14.6	412,627.8	22.22	43.33	412,606.7
Period IIb.								
Subperiod 1......	487,850	734.5	1.50	14.2	447,273.2	22.29	36.92	447,258.6
Subperiod 2......	491,863	737.2	1.00	15.1	451,481.2	22.61	41.28	451,462.0
Subperiod 3......	487,751	738.6	1.10	13.6	450,851.2	22.58	58.41	450,815.3
Subperiod 4......	492,110	737.5	.98	14.1	453,460.5	22.46	26.84	453,456.1
Period IIIb.								
Subperiod 1......	498,006	729.1	1.77	15.1	451,671.8	22.05	45.17	451,648.6
Subperiod 2......	498,848	734.4	2.35	15.4	454,774.7	22.43	58.57	454,738.6
Subperiod 3......	493,745	738.0	1.60	14.1	454,942.9	22.65	59.79	454,905.8
Subperiod 4......	496,321	737.9	1.45	15.4	455,316.7	22.31	64.31	455,274.7

TABLE VII.—*Ingoing air.*

Period.	Aspirator reading.	Barometer.[a]	Temperature.	Reduced aspirator reading, dry.	Volume of carbon dioxid.	Total volume of sample reduced and dry.	Ratio of sample to total ventilation.	Water.		Carbon dioxid.	
								In sample.	In total ventilation.	In sample.	In total ventilation.
Period Ia.	*Liters*	*Mm.*	*°C.*	*Liters.*	*Liters*	*Liters.*	*1:*	*Gram.*	*Grams.*	*Gram.*	*Gms.*
Subperiod 1	200	711.1	20.4	174.12	0.05	174.17	2,344.4	0.0927	217.3	0.1064	294.4
Subperiod 2	200	700.2	21.6	170.76	.05	170.81	2,407.7	.0622	149.8	.1092	262.9
Subperiod 3	200	703.0	21.2	172.25	.05	172.30	2,382.8	.0646	153.9	.1061	252.8
Subperiod 4	200	706.5	20.6	172.87	.05	172.92	2,378.7	.0664	157.9	.1049	249.5
Period IIa.											
Subperiod 1	200	725.7	19.2	178.43	.05	178.48	2,426.3	.1244	301.8	.1062	257.7
Subperiod 2	200	724.7	19.6	177.95	.05	178.00	2,521.8	.0623	157.1	.1047	264.0
Subperiod 3	200	726.5	20.0	178.14	.05	178.19	2,518.9	.0644	162.2	.1013	255.2
Subperiod 4	200	722.7	20.8	176.72	.05	176.77	2,514.5	.0547	137.6	.1053	264.8
Period IIIa.											
Subperiod 1	200	710.2	18.8	174.84	.05	174.89	2,501.3	.0761	190.4	.1053	263.4
Subperiod 2	200	712.2	18.6	175.47	.05	175.52	2,530.6	.0679	171.8	.1040	263.2
Subperiod 3	200	718.6	18.2	177.28	.05	177.33	2,537.8	.0679	172.3	.1043	264.7
Subperiod 4	200	714.4	20.4	174.92	.05	174.97	2,592.0	.0668	173.1	.1074	278.4
Period Ib.											
Subperiod 1	200	726.2	17.4	179.66	.06	179.72	2,348.6	.1188	279.0	.1143	268.4
Subperiod 2	200	720.3	17.0	178.44	.06	178.50	2,365.6	.1653	391.0	.1176	278.2
Subperiod 3	200	718.1	15.4	178.89	.06	178.95	2,316.2	.1146	265.4	.1133	262.4
Subperiod 4	200	714.4	17.2	176.86	.05	176.91	2,332.3	.0582	135.7	.1057	246.5
Period IIb.											
Subperiod 1	200	722.3	19.4	177.47	.05	177.52	2,519.5	.1217	306.6	.1030	259.5
Subperiod 2	200	724.5	16.4	179.85	.05	179.90	2,509.5	.2228	559.1	.1040	261.0
Subperiod 3	200	726.6	18.0	179.39	.05	179.44	2,512.4	.0590	148.2	.1069	268.6
Subperiod 4	200	724.3	17.8	178.95	.05	179.00	2,533.3	.0365	92.46	.1072	271.6
Period IIIb.											
Subperiod 1	200	718.7	20.4	175.99	.05	176.04	2,565.6	.0562	144.2	.1040	266.8
Subperiod 2	200	722.0	16.6	179.10	.05	179.15	2,538.3	.0558	141.6	.1060	269.1
Subperiod 3	200	726.8	17.4	179.80	.05	179.85	2,529.4	.0527	133.3	.1065	269.4
Subperiod 4	200	720.8	19.0	177.34	.05	177.39	2,566.5	.0551	141.4	.1092	280.3

[a] Corrected for tension of aqueous vapor. The air in the aspirator is assumed to be saturated.

TABLE VIII.—*Carbon dioxid.*

Period.	Carbon dioxid in samples (corrected).[a]		Total, Nos. 1 and 2×100 and corrected.[b]	In sample of residual air.	Correction for residual air.	Total CO_2 in outcoming air.	Total CO_2 in ingoing air.	CO_2 added in chamber.	Equivalent carbon.
	Pan No. 1.	Pan No. 2.							
Period Ia.	*Grams.*	*Grams.*	*Grams.*	*Gram.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Subperiod 1	10.9642	11.0337	2,208.4	0.1	+1.0	2,204.5	249.4	1,955.1	533.2
Subperiod 2	11.0263	11.0203	2,208.3	.1	−2.0	2,206.4	262.8	1,943.6	530.0
Subperiod 3	11.1844	11.2091	2,243.0	.1	−1.1	2,242.0	252.8	1,989.2	542.5
Subperiod 4	11.3608	11.2954	2,268.4	.1	+5.9	2,275.3	249.5	2,025.8	552.4
Period IIa.									
Subperiod 1	12.3888	12.4076	2,483.7	.1	−5.1	2,478.7	257.7	2,221.0	605.7
Subperiod 2	13.0521	13.0508	2,614.6	.1	+4.8	2,619.5	264.0	2,355.5	642.3
Subperiod 3	13.0874	13.0295	2,616.0	.1	−4.9	2,611.2	255.2	2,356.1	642.5
Subperiod 4	12.7990	12.8457	2,568.7	.1	+2.4	2,571.2	264.8	2,306.5	629.0
Period IIIa.									
Subperiod 1	12.1124	12.0378	2,419.0	.1	−2.2	2,416.9	263.4	2,153.5	587.3
Subperiod 2	11.6727	11.7236	2,343.5	.1	+5.0	2,348.6	263.2	2,085.4	568.7
Subperiod 3	11.9952	11.9922	2,402.7	.1	−5.0	2,397.8	264.7	2,133.1	581.7
Subperiod 4	11.6808	11.6693	2,338.9	.1	+4.4	2,343.3	278.4	2,064.9	563.1
Period Ib.									
Subperiod 1	11.1265	11.1061	2,226.9	.1	−1.2	2,225.9	268.4	1,957.5	533.8
Subperiod 2	11.3118	11.1981	2,254.7	.1	+ .6	2,255.4	278.2	1,977.2	539.2
Subperiod 3	11.2516	11.3297	2,261.9	.1	+1.2	2,263.2	262.4	2,000.8	[c]545.3
Subperiod 4	11.5985	11.5990	2,323.6	.1	−1.1	2,322.6	246.5	2,076.1	566.2
Period IIb.									
Subperiod 1	12.5948	12.4758	2,511.2	.1	+4.4	2,515.7	259.5	2,256.2	615.3
Subperiod 2	12.7031	12.6671	2,541.2	.1	+1.7	2,543.1	261.0	2,282.1	622.3
Subperiod 3	12.7993	12.6885	2,553.0	.1	+1.0	2,554.1	268.6	2,285.5	[c]623.0
Subperiod 4	12.6649	12.6897	2,539.6	.1	−1.8	2,538.0	271.6	2,266.4	618.0
Period IIIb.									
Subperiod 1	11.7520	11.7364	2,352.7	.1	−2.3	2,350.5	266.8	2,083.7	568.2
Subperiod 2	11.5499	11.6389	2,322.7	.1	+2.6	2,325.4	269.1	2,056.3	560.8
Subperiod 3	11.8184	11.6908	2,354.8	.1	+ .6	2,355.5	269.4	2,086.1	568.9
Subperiod 4	11.8825	11.8158	2,373.7	.1	+5.0	2,378.9	280.3	2,098.6	572.3

[a] For number of pump strokes.
[b] For a slight leakage from the pans, amounting to about 0.165 per cent of the total volume.
[c] Correction applied for man entering chamber, −0.3 gram carbon.

TABLE IX.—*Water.*

Period.	Water in samples (corrected).[a]		Total, Nos. 1 and 2×100 (corrected).[b]	In cans.	On absorbers.	In sample of residual air.	Correction for residual air.	Correction of hygrometer.	Total H_2O in outcoming air + absorbers.	Total H_2O in ingoing air.	Water added in chamber.	Equivalent hydrogen.
	Pan No. 1.	Pan No. 2.										
Period Ia.	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gm.*	*Gm.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*
Subperiod 1	3.7923	3.8547	766.0	1,440.0	0.0	0.1	− 4.0	−5.0	2,197.0	217.3	1,979.7	220.0
Subperiod 2	2.8452	2.8766	573.1	1,626.0	.0	.1	+ 4.4	−5.0	2,198.6	149.8	2,048.8	227.7
Subperiod 3	2.5353	2.5547	509.8	1,577.0	.0	.1	+ 2.7	−5.0	2,079.2	153.9	1,925.3	213.9
Subperiod 4	2.6640	2.6476	532.0	1,517.0	.0	.1	+ .2	−5.0	2,044.3	157.9	1,886.4	209.6
Period IIa.												
Subperiod 1	4.1329	4.1775	832.4	1,740.0	.0	.1	+ 4.4	−5.0	2,571.9	301.8	2,270.1	252.2
Subperiod 2	3.6795	3.6654	735.7	1,824.0	.0	.1	− 2.2	−5.0	2,552.6	157.1	2,395.5	266.2
Subperiod 3	3.6035	3.6398	725.5	1,820.0	.0	.1	− .6	−5.0	2,540.1	162.2	2,377.9	264.2
Subperiod 4	4.0213	4.0380	807.3	1,693.0	.0	.1	+ .3	−5.0	2,495.7	137.5	2,358.2	262.0
Period IIIa.												
Subperiod 1	6.3729	6.4288	1,282.3	1,262.0	.0	.1	+ .5	−5.0	2,539.9	190.4	2,349.5	261.1
Subperiod 2	5.9328	5.9024	1,185.5	1,272.0	.0	.1	+ 2.7	−5.0	2,455.3	171.8	2,283.5	253.7
Subperiod 3	5.1046	5.1016	1,022.3	1,340.0	.0	.1	+ .9	−5.0	2,358.3	172.3	2,186.0	242.9
Subperiod 4	4.2235	4.2406	847.8	1,695.0	.0	.1	− .3	−5.0	2,537.7	173.1	2,364.5	262.7
Period Ib.												
Subperiod 1	3.0157	3.0425	606.8	928.0	.0	.1	− 8.0	−5.0	1,521.9	279.0	1.242.9	138.1
Subperiod 2	2.3775	2.3810	476.6	1,303.0	.0	.1	+11.7	−5.0	1,786.4	391.0	1,395.4	155.0
Subperiod 3	2.5541	2.5526	511.5	1,138.0	.0	.1	− 1.8	−5.0	1,642.8	265.4	1,377.4	[c]153.0
Subperiod 4	2.3299	2.3264	466.4	1,173.0	.0	.1	− .3	−5.0	1.634.2	135.7	1,498.5	166.5
Period IIb.												
Subperiod 1	3.6076	3.6374	725.7	1,248.0	.0	.1	+22.0	−5.0	1,990.8	306.6	1,684.2	187.1
Subperiod 2	2.4445	2.4569	491.2	1,734.0	.0	.1	−11.8	−5.0	2,208.5	559.1	1,649.4	183.3
Subperiod 3	2.7217	2.7077	543.8	1,390.0	.0	.1	+ 2.0	−5.0	1,930.9	148.2	1,782.7	[c]198.0
Subperiod 4	2.4214	2.4335	486.3	1,385.0	.0	.1	− 1.2	−5.0	1,865.2	92.5	1,772.7	197.0
Period IIIb.												
Subperiod 1	4.4379	4.4660	891.9	1,016.0	.0	.1	− 2.3	−5.0	1,900.7	144.2	1,756.5	195.2
Subperiod 2	3.6533	3.6412	730.7	1,034.0	.0	.1	+ 4.8	−5.0	1,764.5	141.6	1,622.9	180.3
Subperiod 3	3.9753	3.9933	798.2	1,025.0	.0	.1	+ 8.3	−5.0	1,826.6	133.3	1,693.3	188.2
Subperiod 4	3.6247	3.6324	726.9	1,274.0	.0	.1	− 3.1	−5.0	1,992.9	141.4	1,851.5	205.7

[a] For number of pump strokes.

[b] For slight leakage from pans, see previous table.

[c] Correction applied for man entering chamber −0.05 gram hydrogen.

TABLE X.—*Carbon and hydrogen in combustible gases.*

Period.	Total CO_2 weighed ×200 (corrected).[a]	Correction for ingoing air.	Carbon as hydrocarbon.	Total H_2O weighed ×200 (corrected).[a]	Correction for ingoing air.	Hydrogen as hydrocarbon.	Methane, CO_2× .3643.
Period Ia.							
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Subperiod 1	98.26	−3.04	25.97	79.69	−7.42	8.03	35.80
Subperiod 2	88.15	−3.06	23.20	72.54	−7.47	7.23	32.11
Subperiod 3	96.20	−3.05	25.40	79.65	−7.46	8.02	35.05
Subperiod 4	103.47	−3.06	27.39	85.72	−7.47	8.69	37.69
Period IIa.							
Subperiod 1	118.37	−3.22	31.40	97.12	−7.86	9.92	43.12
Subperiod 2	156.18	−3.34	41.68	126.83	−8.15	13.19	56.90
Subperiod 3	144.34	−3.34	38.45	119.36	−8.15	12.36	52.58
Subperiod 4	96.54	−3.30	25.43	79.23	−8.07	7.91	35.17
Period IIIa.							
Subperiod 1	106.02	−3.25	28.03	87.95	−7.94	8.89	38.62
Subperiod 2	128.22	−3.30	34.07	106.00	−8.07	10.88	46.71
Subperiod 3	95.32	−3.35	25.08	79.17	−8.17	7.89	34.73
Subperiod 4	103.71	−3.37	27.36	85.92	−8.24	8.63	37.78
Period Ib.							
Subperiod 1	96.12	−3.14	25.36	76.67	−7.67	7.67	35.02
Subperiod 2	88.35	−3.14	23.24	71.18	−7.67	7.06	32.19
Subperiod 3	97.74	−3.37	25.73	84.68	−8.24	8.49	35.61
Subperiod 4	87.94	−3.07	23.14	71.86	−7.49	7.15	32.04
Period IIb.							
Subperiod 1	75.64	−3.33	19.72	62.94	−8.12	6.09	27.56
Subperiod 2	84.22	−3.36	22.05	75.10	−8.20	7.43	30.68
Subperiod 3	117.75	−3.35	31.20	96.36	−8.19	9.80	42.90
Subperiod 4	....	....	....	....	....	....	....
Period IIIb.							
Subperiod 1	91.83	−3.36	24.13	73.50	−8.20	7.26	33.45
Subperiod 2	118.09	−3.38	31.28	98.54	−8.26	10.03	43.02
Subperiod 3	120.50	−3.38	31.94	101.83	−8.26	10.40	43.90
Subperiod 4	129.35	−3.39	34.35	107.78	−8.27	11.06	47.12

[a] For slight leakage from pans, see previous table.

TABLE XI.—*Heat measurements.*

Period.	Relative rate of flow.	Average temperature of water current.					Total water.	Average specific heat of water.	Heat produced in absorbers.		Total heat, calories at 20.°
		Ingoing.	Outcoming.	Difference.	Correction for pressure.	Corrected difference.			Difference of pressure.	Equivalent heat.	
PERIOD Ia.											
Subperiod 1.		°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	*Liters.*		*Cm.*	*Cal.*	
6 p. m. to 6.51 p. m.	29.0	7.5062	12.5308	5.0246	+0.0008	5.0254	59.00	1.0030	0.40	0.01	297.38
6.51 p. m. to 11.59 p. m.	30.0	6.8605	10.7945	3.9340	.0010	3.9350	490.00	1.0035	.50	.08	1,934.82
11.59 p. m. to 12.40 a. m.	28.0	6.6220	12.0500	5.4280	.0006	5.4286	35.00	1.0033	.30	......	190.64
12.40 a. m. to 1.08 a. m.	27.0	6.8814	13.5243	6.6429	.0004	6.6433	16.00	1.0030	.20	......	106.61
1.08 a. m. to 2.13 a. m.	28.0	6.0665	12.2594	6.1929	.0006	6.1935	55.00	1.0035	.30	.01	341.82
2.13 a. m. to 6 a. m.	30.0	5.0205	9.6850	4.6645	.0010	4.6655	349.50	1.0044	.50	.06	1,637.71
											4,508.98
Latent heat of water vapor											1,171.99
Correction for feed, water, excreta, and vessels											−13.05
Total heat											5,667.92
Subperiod 2.											
6 a. m. to 8.17 a. m.	30.0	5.2237	9.3171	4.0934	.0010	4.0944	209.00	1.0044	.50	.03	859.46
8.17 a. m. to 9.06 a. m.	29.0	5.4425	10.1983	4.7558	.0008	4.7566	60.00	1.0041	.40	.01	286.55
9.06 a. m. to 10.14 a. m.	28.0	5.7324	11.4200	5.6876	.0006	5.6882	60.00	1.0038	.30	.01	342.58
10.14 a. m. to 11.39 a. m.	27.0	6.4975	13.6640	7.1665	.0004	7.1669	44.50	1.0031	.20	......	319.92
11.39 a. m. to 6 p. m.	28.0	6.2513	12.8185	6.5672	.0006	6.5678	331.50	1.0033	.30	.03	2,184.38
											3,992.89
Latent heat of water vapor											1,212.91
Correction for feed, water, excreta, and vessels											+8.00
Total heat											5,213.80
Subperiod 3.											
6 p. m. to 6.42 p. m.	28.0	6.3282	12.9191	6.5909	.0006	6.5915	38.00	1.0032	.30	......	251.28
6.42 p. m. to 7.46 p. m.	29.0	6.0525	11.4269	5.3744	.0008	5.3752	76.50	1.0036	.40	.01	412.67
7.46 p. m. to 7.51 p. m.	28.0	6.1400	11.4200	5.2800	.0006	5.2806	5.00	1.0036	.30	......	26.50
7.51 p. m. to 12.58 a. m.	29.0	6.0323	11.6083	5.5760	.0008	5.5768	351.50	1.0036	.40	.04	1,967.26
12.58 a. m. to 2 a. m.	28.0	6.2820	12.0880	5.8060	.0006	5.8066	51.00	1.0034	.30	......	297.14
2 a. m. to 3.08 a. m.	27.0	6.6006	13.5171	6.9165	.0004	6.9169	41.00	1.0030	.20	......	284.44
3.08 a. m. to 6 a. m.	29.0	5.9584	11.1751	5.2167	.0008	5.2175	220.50	1.0037	.40	.03	1,154.69
											4,393.98
Latent heat of water vapor											1,139.76
Correction for feed, water, excreta, and vessels											−11.41
Total heat											5,522.33
Subperiod 4.											
6 a. m. to 9.40 a. m.	29.0	6.0129	10.9675	4.9546	.0008	4.9554	279.00	1.0037	.40	.04	1,387.63
9.40 a. m. to 6 p. m.	29.0	6.1229	11.2345	5.1116	.0008	5.1124	602.00	1.0031	.40	.08	3,087.13
											4,474.76
Latent heat of water vapor											1,116.73
Correction for feed, water, excreta, and vessels											+14.07
Total heat											5,605.56

TABLE XI.—*Heat measurements*—Continued.

Period.	Relative rate of flow.	Average temperature of water current.					Total water.	Average specific heat of water.	Heat produced in absorbers.		Total heat, calories at 20°.
		Ingoing.	Outcoming.	Difference.	Correction for pressure.	Corrected difference.			Difference of pressure.	Equivalent heat.	
PERIOD IIa.											
Subperiod 1.		°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	*Liters.*		*Cm.*	*Cal.*	
6 p. m. to 7.23 p. m.	28.0	5.0676	12.4276	7.3600	+0.0006	7.3606	67.50	1.0037	0.30	......	498.68
7.23 p. m. to 2.36 a. m.	29.0	4.1681	9.6580	5.4899	.0008	5.4907	517.50	1.0046	.40	0.07	2,854.44
2.36 a. m. to 3.04 a. m.	28.0	3.9163	9.6438	5.7275	.0006	5.7281	26.00	1.0044	.30	......	149.58
3.04 a. m. to 5.01 a. m.	27.0	4.5355	12.4741	7.9386	.0004	7.9390	62.00	1.0038	.20	......	494.09
5.01 a. m. to 6 a. m.	29.0	3.4421	9.3100	5.8679	.0008	5.8687	73.00	1.0049	.40	.01	430.50
											4,427.29
Latent heat of water vapor											1,343.90
Correction for feed, water, excreta, and vessels											—5.28
Total heat											5,765.91
Subperiod 2											
6 a. m. to 9.41 a. m.	29.0	3.2498	8.4346	5.1848	.0008	5.1856	277.00	1.0052	.40	.03	1,443.85
9.41 a. m. to 12.46 p. m.	27.0	4.1857	11.9750	7.7893	.0004	7.7897	102.00	1.0040	.20	......	797.73
12.46 p. m. to 2.46 p. m.	29.0	3.5490	9.6357	6.0867	.0008	6.0875	140.00	1.0048	.40	.02	856.32
2.46 p. m. to 4.29 p. m.	27.0	4.8046	12.9669	8.1623	.0004	8.1627	50.50	1.0037	.20	......	413.74
4.29 p. m. to 6 p. m.	29.0	3.9145	9.8682	5.9537	.0008	5.9545	105.83	1.0046	.40	.01	633.05
											4,144.69
Latent heat of water vapor											1,418.15
Correction for feed, water, excreta, and vessels											+76.44
Total heat											5,639.28
Subperiod 3.											
6 p. m. to 8.55 p. m.	29.0	3.8551	9.9025	6.0474	.0008	6.0482	198.00	1.0046	.40	.02	1,203.03
8.55 p. m. to 9.23 p. m.	27.0	4.6557	12.5771	7.9214	.0004	7.9218	12.00	1.0038	.20	......	95.42
9.23 p. m. to 10.42 p. m.	28.0	4.1560	11.2200	7.0640	.0006	7.0646	60.00	1.0042	.30	......	425.66
10.42 p. m. to 2.05 a. m.	29.0	3.5025	9.7694	6.2669	.0008	6.2677	230.00	1.0048	.40	.03	1,448.46
2.05 a. m. to 2.35 a. m.	28.0	3.8671	10.0114	6.1443	.0006	6.1449	26.00	1.0046	.30	......	160.50
2.35 a. m. to 4.33 a. m.	27.0	4.6323	13.2696	8.6373	.0004	8.6377	61.00	1.0037	.20	......	528.85
4.33 a. m. to 6 a. m.	29 0	3.4147	9.2357	5.8210	.0008	5.8218	108.75	1.0050	.40	.01	636.28
											4,498.20
Latent heat of water vapor											1,407.70
Correction for feed, water, excreta, and vessels											−3.94
Total heat											5,901.96
Subperiod 4.											
6 a. m. to 8.12 a. m.	29.0	3.4053	8.9379	5.5326	.0008	5.5334	160.00	1.0050	.40	.02	889.75
8.12 a. m. to 9.48 a. m.	27.0	4.7396	13.1496	8.4100	.0004	8.4104	46.00	1.0037	.20	......	388.31
9.48 a. m. to 10.33 a. m.	28.0	4.0182	10.9500	6.9318	.0006	6.9324	34.00	1.0043	.30	......	236.72
10.33 a. m. to 10.36 a. m.	27.0	4.3700	11.9800	7.6100	.0004	7.6104	1.00	1.0040	.20	......	7.64
10.36 a. m. to 1.07 p. m.	29.0	3.7216	9.6248	5.9032	.0008	5.9040	177.75	1.0047	.40	.02	1,054.01
1.07 p. m. to 1.42 p. m.	27.0	5.1844	12.5688	7.3844	.0004	7.3848	17.25	1.0037	.20	......	127.86
1.42 p. m. to 2.49 p. m.	28.0	4.7962	11.0456	6.2494	.0006	6.2500	56.00	1.0040	.30	......	351.40
2.49 p. m. to 6 p. m.	29.0	4.8045	9.9883	5.1838	.0008	5.1846	239.00	1.0043	.40	.03	1,244.42
											4,300.11
Latent heat of water vapor											1,396.04
Correction for feed, water, excreta, and vessels											+25.76
Total heat											5,721.91

TABLE XI.—*Heat measurements*—Continued.

Period.	Relative rate of flow.	Average temperature of water current.					Total water.	Average specific heat of water.	Heat produced in absorbers.		Total heat, calories at 20°.
		Ingoing.	Outcoming.	Difference.	Correction for pressure.	Corrected difference.			Difference of pressure.	Equivalent heat.	
PERIOD III*a*.											
Subperiod 1.		°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	*Liters.*		*Cm.*	*Cal.*	
6 p. m. to 8.57 p. m.	29.0	6.4284	11.4346	5.0062	+0.0008	5.0070	215.00	1.0035	0.40	0.03	1,080.24
8.57 p. m. to 9.23 p. m.	28.0	6.3200	12.2583	5.9383	.0006	5.9389	21.00	1.0034	.30	.....	125.14
9.23 p. m. to 9.36 p. m.	27.0	6.6400	13.1300	6.4900	.0004	6.4904	5.50	1.0029	.20	.....	35.80
9.36 p. m. to 2.53 a. m.	29.0	5.6846	11.3675	5.6829	.0008	5.6837	351.50	1.0037	.40	.04	2,005.17
2.53 a. m. to 4.24 a. m.	27.0	6.1169	13.7538	7.6369	.0004	7.6373	47.00	1.0028	.20	.....	359.95
4.24 a. m. to 4.55 a. m.	28.0	5.7100	12.2987	6.5887	.0006	6.5893	26.00	1.0035	.30	.....	171.92
4.55 a. m. to 4.58 a. m.	27.0	5.7000	12.2000	6.5000	.0004	6.5004	1.50	1.0035	.20	.....	9.78
4.58 a. m. to 6 a. m.	29.0	5.2827	10.6780	5.3953	.0008	5.3961	75.50	1.0040	.40	.01	409.02
											4,197.02
Latent heat of water vapor											1,390.93
Correction for feed, water, excreta, and vessels											−.98
Total heat											5,586.97
Subperiod 2.											
6 a. m. to 8.31 a. m.	29.0	4.1684	10.6034	5.2581	.0008	5.2589	178.00	1.0040	.40	.02	939.80
8.31 a. m. to 9.16 a. m.	27.0	6.5208	13.7475	4.2267	.0004	4.2271	22.00	1.0030	.20	.....	93.27
9.16 a. m. to 10.10 a. m.	27.5	6.2800	13.5908	7.3108	.0005	7.3113	34.50	1.0031	.25	.....	253.02
10.10 a. m. to 11.46 a. m.	29.0	5.4408	11.2941	5.8533	.0008	5.8541	110.50	1.0038	.40	.01	649.32
11.46 a. m to 12.06 p. m.	27.0	6.1020	13.4140	7.3120	.0004	7.3124	10.00	1.0032	.20	.....	73.35
12.06 p. m. to 12.32 p. m.	27.5	6.0886	13.3714	7.2828	.0005	7.2833	17.00	1.0032	.25	.....	124.21
12.32 p. m. to 1.31 p. m.	27.0	6.4521	14.2535	7.8014	.0004	7.8018	28.00	1.0030	.20	.....	219.10
1.31 p. m. to 2.27 p. m.	27.5	6.2457	13.1750	6.9293	.0005	6.9298	38.00	1.0031	.25	.....	264.14
2.27 p. m. to 5.46 p. m.	29.0	5.9192	11.4074	5.4882	.0008	5.4890	230.50	1.0036	.40	.29	1,269.47
5.46 p. m. to 6 p. m.	27.0	6.4500	12.5867	6.1367	.0004	6.1371	7.50	1.0032	.20	.....	46.17
											3,931.85
Latent heat of water vapor											1,351.83
Correction for feed water, excreta, and vessels											+39.23
Total heat											5,322.91
Subperiod 3.											
6 p. m. to 7.46 p. m.	29.0	6.0941	11.6382	5.5441	.0008	5.5449	119.00	1.0036	.40	.01	662.20
7.46 p. m. to 8.23 p. m.	27.0	6.6267	13.5767	6.9500	.0004	6.9504	20.50	1.0030	.20	.....	142.91
8.23 p. m. to 9.20 p. m.	27.5	6.4292	13.2823	6.8531	.0005	6.8536	41.50	1.0031	.25	.....	284.30
9.20 p. m. to 9.54 p. m.	29.0	6.0600	11.6722	5.6122	.0008	5.6130	39.00	1.0036	.40	.01	219.68
9.54 p. m. to 10.24 p. m.	30.0	5.8562	10.6737	4.8175	.0010	4.8185	47.00	1.0038	.50	.01	227.32
10.24 p. m. to 11.22 p. m.	27.5	6.4693	13.6950	7.2257	.0005	7.2262	33.00	1.0030	.25	.....	239.17
11.22 p. m. to 11.58 p. m.	28.0	6.0555	12.9766	6.9211	.0006	6.9217	27.00	1.0033	.30	.....	187.50
11.58 p. m. to 12.22 a. m.	29.0	5.5767	11.6950	6.1183	.0008	6.1191	29.00	1.0037	.40	.....	178.11
12.22 a. m. to 12.25 a. m.	30.0	5.5000	11.2200	5.7200	.0010	5.7210	2.50	1.0038	.50	.....	14.35
12.25 a. m. to 2.09 a. m.	27.5	5.8604	13.6731	7.8127	.0005	7.8132	62.50	1.0032	.25	.....	489.88
2.09 a. m. to 2.18 a. m.	29.0	5.2300	12.1500	6.9200	.0008	6.9208	10.00	1.0037	.40	.....	69.46
2.18 a. m. to 3.04 a. m.	30.0	4.6850	10.0817	5.3967	.0010	5.3977	67.00	1.0043	.50	.01	363.19
3.04 a. m. to 4.59 a. m.	27.5	5.0235	12.5089	7.4854	.0005	7.4859	75.00	1.0037	.25	.....	563.52
4.59 a. m. to 5.34 a. m.	30.0	4.1700	10.0089	5.8389	.0010	5.8399	46.00	1.0045	.50	.01	269.83
5.34 a. m. to 5.44 a. m.	29.0	4.1950	10.1000	5.9050	.0008	5.9058	10.50	1.0045	.40	.....	62.29
5.44 a. m. to 6 a. m.	27.0	4.8325	12.4875	7.6550	.0004	7.6554	7.25	1.0038	.20	.....	55.71
											4,029.42
Latent heat of water vapor											1,294.10
Correction for feed, water, excreta, and vessels											+.96
Total heat											5,234.48

TABLE XI.—*Heat measurements*—Continued.

Period.	Relative rate of flow.	Average temperature of water current.					Total water.	Average specific heat of water.	Heat produced in absorbers.		Total heat, calories at 20°.
		Ingoing.	Outcoming.	Difference.	Correction for pressure.	Corrected difference.			Difference of pressure.	Equivalent heat.	
PERIOD III*a*—Cont'd.											
Subperiod 4.		°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	*Liters.*		*Cm.*	*Cal.*	
6 a. m. to 7.16 a. m.	29.0	4.1684	10.7689	6.6005	0.0008	6.6013	82.00	1.0043	0.40	0.01	543.62
7.16 a. m. to 9.30 a. m.	28.0	4.5500	12.0151	7.4651	.0006	7.4657	102.00	1.0039	.30	.01	764.46
9.30 a. m. to 10.07 a. m.	27.0	5.3700	13.8244	8.4544	.0004	8.4548	16.00	1.0034	.20	......	135.73
10.07 a. m. to 10.46 a. m.	27.5	5.1550	13.3570	8.2020	.0005	8.2025	23.00	1.0032	.25	......	189.26
10.46 a. m. to 11.36 a. m.	27.0	5.5208	14.0777	8.5569	.0004	8.5573	23.00	1.0033	.20	......	197.46
11.36 a. m. to 12.22 p. m.	28.0	4.9227	13.1027	8.1800	.0006	8.1806	33.00	1.0036	.30	......	270.93
12.22 p. m. to 1.37 p. m.	29.0	4.6826	11.8158	7.1332	.0008	7.1340	68.00	1.0040	.40	.01	487.04
1.37 p. m. to 1.58 p. m.	27.0	5.4100	13.4140	8.0040	.0004	8.0044	7.95	1.0034	.20	......	62.24
1.58 p. m. to 3.56 p. m.	27.5	5.8213	13.9290	8.1077	.0005	8.1082	61.25	1.0032	.25	......	498.21
3.56 p. m. to 5.27 p. m.	29.0	5.2195	11.3545	6.1350	.0008	6.1358	96.00	1.0039	.40	.01	591.32
5.27 p. m. to 6 p. m.	28.5	5.4100	11.7100	6.3000	.0007	6.3007	28.75	1.0037	.35	......	181.81
											3,922.08
Latent heat of water vapor											1,399.81
Correction for feed, water, excreta, and vessels											+29.07
Total heat											5,350.96
PERIOD I*b*.											
Subperiod 1.											
6 p. m. to 6.23 p. m.	45.0	3.1883	4.2750	1.0867	+0.0162	1.1029	148.00	1.0064	9.15	.43	163.84
6.23 p. m. to 12.11 a. m.	47.0	2.8406	3.9274	1.0868	.0196	1.1064	2,236.00	1.0067	10.25	7.27	2,492.75
12.11 a. m. to 1.14 a. m.	49.0	2.8613	3.9106	1.0493	.0230	1.0723	416.00	1.0067	11.25	1.48	447.58
1.14 a. m. to 6. a. m.	51.0	2.8275	3.8159	.9884	.0266	1.0150	1,969.00	1.0062	12.25	7.60	2,003.33
											5,107.50
Latent heat of water vapor											735.76
Correction for feed, water, excreta, and vessels											−15.27
Total heat											5,827.99
Subperiod 2.											
6 a. m. to 6.20 a. m.	51.0	......	......	......	......	......	130.00	......	......	......	....
6.20 a. m. to 8.28 a. m.	85.0	......	......	......	......	......	114.00	......	......	......	....
8.28 a. m. to 9.10 a. m.	50.0	6.2910	7.0260	.7350	.0248	.7598	298.00	1.0046	11.75	1.09	226.37
9.10 a. m. to 9.28 a. m.	42.0	6.6400	7.6620	1.0220	.0122	1.0342	88.00	1.0043	7.00	.20	91.20
9.28 a. m. to 11.37 a. m.	38.0	4.2800	5.9606	1.6806	.0074	1.6880	470.00	1.0055	4.00	.60	792.12
11.37 a. m. to 12.21 p. m.	42.0	3.3818	4.8290	1.4472	.0122	1.4594	200.00	1.0061	7.00	.44	293.22
12.21 p. m. to 1.46 p. m.	38.0	4.0405	5.8333	1.7928	.0074	1.8002	300.00	1.0056	4.00	.38	542.70
1.46 p. m. to 3.25 p. m.	39.0	2.5652	4.9284	2.3632	.0086	2.3718	300.00	1.0064	4.75	.45	715.64
3.25 p. m. to 4 p. m.	40.0	2.2245	4.7922	2.5677	.0098	2.5775	100.00	1.0066	5.60	.18	259.27
4 p. m. to 4.18 p. m.	41.0	2.2325	4.8800	2.6475	.0110	2.6585	44.00	1.0066	6.30	.09	117.65
4.18 p. m. to 4.28 p. m.	43.0	1.9650	4.6700	2.7050	.0134	2.7184	32.00	1.0067	7.75	.08	87.49
4.28 p. m. to 4.43 p. m.	45.0	1.7625	4.4625	2.7000	.0162	2.7162	35.00	1.0068	9.15	.10	95.61
4.43 p. m. to 6 p. m.	48.0	2.0400	4.7179	2.6779	.0213	2.6992	200.25	1.0066	10.75	.68	543.40
											3,764.67
Latent heat of water vapor											826.05
Correction for feed, water, excreta, and vessels											−19.09
Total heat											4,571.63
Subperiod 3.											
6 p. m to 5.02 a. m.	48.0	2.8490	4.2419	1.3929	.0213	1.4142	3,320.00	1.0065	10.75	11.43	4,714.23
5.02 a. m. to 5.46 a. m.	50.0	2.6891	4.1482	1.4591	.0248	1.4839	232.00	1.0066	11.75	.85	345.69
5.46 a. m. to 6. a. m.	49.0	2.1633	3.5967	1.4334	.0266	1.4600	68.00	1.0070	11.25	.24	99.73
											5,159.65

TABLE XI.—*Heat measurements*—Continued.

Period.	Relative rate of flow.	Average temperature of water current.					Total water.	Average specific heat of water.	Heat produced in absorbers.		Total heat, calories at 20°.
		Ingoing.	Outcoming.	Difference.	Correction for pressure.	Corrected difference.			Difference of pressure.	Equivalent heat.	
PERIOD I*b*—Cont'd.											
Subperiod 3.—Cont'd.											
		°C.	*°C.*	*°C.*	*°C.*	*°C.*	*Liters.*		*Cm.*	*Cal.*	
Latent heat of water vapor											815.39
Correction for feed, water, excreta, and vessels											−18.09
Total heat											5,956.95
Subperiod 4.											
6 a. m. to 9.31 a. m.	49.0	3.5877	5.0707	1.4830	0.0230	1.5060	932.00	1.0062	11.25	3.32	1,408.57
9.31 a. m. to 10.10 a. m.	47.0	4.2560	5.7180	1.4620	.0196	1.4816	168.00	1.0056	10.25	.55	249.75
10.10 a. m. to 11.38 a. m.	43.0	3.9250	5.8359	1.9109	.0134	1.9243	300.00	1.0057	7.75	.74	579.84
11.38 a. m. to 1 p. m.	43.0	3.2415	5.8280	2.5865	.0134	2.5999	200.00	1.0059	7.75	.49	522.56
1 p. m. to 6 p. m.	47.0	2.3776	5.2708	2.8932	.0196	2.9128	718.00	1.0064	10.25	2.33	2,102.45
											4,863.17
Latent heat of water vapor											887.11
Correction for feed, water, excreta, and vessels											−10.32
Total heat											5,739.96
PERIOD II*b*.											
Subperiod 1.											
6 p. m. to 6.35 p. m.	32.0	2.5389	5.3778	2.8389	+0.0020	2.8409	78.00	1.0063	1.00	.02	222.97
6.35 p. m. to 6.55 p. m.	33.0	2.4440	4.9800	2.5360	.0024	2.5384	55.00	1.0064	1.50	.03	140.48
6.55 p. m. to 7.17 p. m.	34.0	2.3800	4.6200	2.2400	.0032	2.2432	67.00	1.0066	2.00	.04	151.25
7.17 p. m. to 11.05 p. m.	35.0	2.4491	4.4033	1.9542	.0040	1.9582	800.00	1.0066	2.50	.63	1,576.27
11.05 p. m. to 1.51 a. m.	36.0	2.2898	4.1261	1.8363	.0050	1.8413	645.00	1.0068	3.00	.61	1,195.10
1.51 a. m. to 1.56 a. m.	33.0	2.2650	4,0600	1.7950	.0024	1.7974	18.00	1.0068	1.50	,01	32.56
1.56 a. m. to 3.29 a. m.	36.0	2.1744	3.9557	1.7813	.0050	1.7863	370.00	1.0068	3.00	.35	665.08
3.29 a. m. to 3.49 a. m.	33.0	2.2875	4.1850	1.8975	.0024	1.8999	50.00	1.0067	1.50	.02	95.61
3.49 a. m. to 4.39 a. m.	34.0	2.2138	3.8938	1.6800	.0032	1.6832	160.00	1.0069	2.00	.10	271.07
4.39 a. m. to 4.53 a. m.	32.0	2.3300	4.4766	2.1466	.0020	2.1486	31.00	1.0066	1.00	.01	67.04
4.53 a. m. to 5.46 a. m.	30.0	2.5114	5.5164	3.0050	.0010	3.0060	85.00	1.0063	50	.01	257.11
5.46 a. m. to 5.52 a. m.	33.0	2.1800	4.8500	2.6700	.0024	2.6724	16.00	1.0066	1.50	.01	43.03
5.52 a. m. to 5.57 a. m.	35.0	2.0500	4.1300	2.0800	.0040	2.0840	23.00	1.0069	2.50	.02	48.24
5.57 a. m. to 6 a. m.	37.0	1.9850	3.8450	1.8600	.0062	1.8662	13.00	1.0069	3.50		24.43
											4,790.24
Latent heat of water vapor											997.05
Correction for feed, water, excreta, and vessels											−14.23
Total heat											5,773.06
Subperiod 2.											
6 a. m. to 7.33 a. m.	37.0	1.9696	3.7492	1.7796	.0062	1.7858	383.00	1.0070	3.50	.43	688.32
7.33 a. m. to 1.14 p. m.	36.0	2.4865	4.1986	1.7121	.0050	1.7171	1,238.00	1.0067	3.00	1.18	2,138.83
1.14 p. m. to 1.29 p. m.	34.0	2.7550	4.6325	1.8775	.0032	1.8807	44.00	1.0064	2.00	.03	83.25
1.29 p. m. to 1.43 p. m.	33.0	2.7833	4.7466	1.9633	.0024	1.9657	35.00	1.0064	1.50	.02	69.22
1.43 p. m. to 2.06 p. m.	32.0	2.8850	5.1383	2.2533	.0020	2.2553	46.50	1.0048	1.00	.01	105.36
2.06 p. m. to 3.26 p. m.	30.0	3.2140	6.4190	3.2050	.0010	3.2060	100.50	1.0057	.50	.02	324.02
3.26 p. m. to 6 p. m.	37.0	2.7226	5.4550	1.7324	.0062	1.7386	597.50	1.0062	3.50	.66	1,044.59
											4,453.59
Latent heat of water vapor											976.42
Correction for feed, water, excreta, and vessels											−129.24
Total heat											5,300.77

TABLE XI.—*Heat measurements*—Continued.

Period.	Relative rate of flow.	Average temperature of water current.					Total water.	Average specific heat of water.	Heat produced in absorbers.		Total heat, calories at 20°.
		Ingoing.	Outcoming.	Difference.	Correction for pressure.	Corrected difference.			Difference of pressure.	Equivalent heat.	
PERIOD II*b*—Cont'd.											
Subperiod 3.		°*C*	°*C*	°*C*	°*C*	°*C*	*Liters.*		*Cm.*	*Cal.*	
6 p. m. to 7.59 p. m.	37.0	2.5843	4.2926	1.7083	0.0062	1.7145	472.00	1.0066	3.50	0.52	814.07
7.59 p. m. to 10.38 p. m.	34.0	2.5803	4.4635	1.8832	.0032	1.8864	454.00	1.0065	2.00	.29	861.70
10.38 p. m. to 10.56 p. m.	37.0	2.4100	4.1220	1.7120	.0062	1.7182	74.00	1.0069	3.50	.08	127.94
10.56 p. m. to 11.07 p. m.	39.0	2.3650	3.9200	1.5550	.0086	1.5636	55.00	1.0068	4.75	.08	86.50
11.07 p. m. to 11.42 p. m.	41.0	2.3478	3.7645	1.4167	.0110	1.4277	189.00	1.0069	6.30	.38	271.32
11.42 p. m. to 12.42 a. m.	34.0	2.4747	4.4027	1.9280	.0032	1.9312	184.00	1.0066	2.00	.12	357.57
12.42 a. m. to 1.51 a. m.	32.0	2.4647	4.8665	2.4018	.0020	2.4038	158.00	1.0065	1.00	.05	382.22
1.51 a. m. to 2.02 a. m.	37.0	2.2533	4.3900	2.1367	.0062	2.1429	23.00	1.0067	3.50	.03	49.59
2.02 a. m. to 2.48 a. m.	.....	.....	.....	.....	.....	.....	2.00	.....	.....	.....	.....
2.48 a. m. to 3.16 a. m.	37.0	3.2729	6.2943	3.0214	.0062	3.0276	89.00	1.0058	3.50	.10	270.92
3.16 a. m. to 3.34 a. m.	38.0	3.0420	5.2260	2.1840	.0074	2.1914	62.00	1.0062	4.00	.08	136.63
3.34 a. m. to 5.17 a. m.	40.0	2.6096	3.9588	1.3492	.0098	1.3590	538.00	1.0067	5.60	.96	735.08
5.17 a. m. to 6 a. m.	42.0	2.3820	3.7540	1.3720	.0122	1.3842	240.00	1.0068	7.00	.53	333.94
											4,427.48
Latent heat of water vapor											1,058.32
Correction for feed, water, excreta, and vessels											−25.61
Total heat											5,460.19
Subperiod 4.											
6 a. m. to 7.10 a. m.	42.0	2.3500	3.7078	1.3578	.0122	1.3700	409.00	1.0069	7.00	.91	563.29
7.10 a. m. to 8.11 a. m.	40.0	2.4373	3.8406	1.4033	.0098	1.4131	306.00	1.0068	5.60	.55	434.80
8.11 a. m. to 8.59 a. m.	38.0	2.5150	4.0800	1.5650	.0074	1.5724	207.00	1.0067	4.00	.26	327.41
8.59 a. m. to 9.16 a. m.	33.0	2.6275	4.6525	2.0250	.0024	2.0274	35.00	1.0065	1.50	.02	71.40
9.16 a. m. to 10.26 a. m.	32.0	2.7522	5.0372	2.2850	.0020	2.2870	166.50	1.0063	1.00	.53	382.65
10.26 a. m. to 1.24 p. m.	37.0	2.6136	4.3141	1.7005	.0062	1.7067	700.50	1.0066	3.50	.78	1,202.65
1.24 p. m. to 1.26 p. m.	35.0	2.8500	4.3900	1.5400	.0040	1.5440	6.00	1.0065	2.50	.....	9.32
1.26 p. m. to 2.20 p. m.	31.0	3.1177	5.6615	2.5438	.0012	2.5450	98.00	1.0056	.75	.02	250.79
2.20 p. m. to 2.40 p. m.	37.0	2.8380	4.6020	1.7640	.0062	1.7702	78.00	1.0064	3.50	.09	138.87
2.40 p. m. to 2.53 p. m.	39.0	2.8075	4.2975	1.4900	.0086	1.4986	64.00	1.0065	4.75	.10	96.43
2.53 p. m. to 6 p. m.	41.0	2.7161	3.9972	1.2811	.0110	1.2921	1,003.75	1.0066	6.30	2.00	1.303.50
											4,781.11
Latent heat of water vapor											1,049.46
Correction for feed, water, excreta, and vessels											−42.09
Total heat											5,788.48
PERIOD III*b*.											
Subperiod 1.											
6 p. m. to 10.27 p. m.	35.0	2.4247	4.8101	2.3354	+0.0040	2.3894	762.50	1.0065	2.50	.60	1,833.76
10.27 p. m. to 10.45 p. m.	33.0	2.5340	4.8140	2.2800	.0024	2.2824	43.50	1.0065	1.50	.02	99.91
10.45 p. m. to 12.21 a. m.	30.0	2.9704	6.4647	3.4943	.0010	3.4953	135.00	1.0058	.50	.02	474.58
12.21 a. m. to 12.38 a. m.	35.0	2.6560	5.2800	2.6240	.0040	2.6280	46.00	1.0063	2.50	.04	121.61
12.38 a. m. to 2.05 a. m.	37.0	2.5641	4.7613	2.1972	.0062	2.2034	284.00	1.0065	3.50	.32	629.51
2.05 a. m. to 3.31 a. m.	32.0	2.6633	5.2290	2.5657	.0020	2.5677	177.00	1.0063	1.00	.06	457.29
3.31 a. m. to 4.18 a. m.	35.0	2.3025	4.7758	2.4733	.0040	2.4773	139.00	1.0066	2.50	.11	346.51
4.18 a. m. to 6 a. m.	36.0	2.1496	4.3460	2.1964	.0050	2.2014	315.34	1.0067	3.00	.30	698.54
											4,661.11
Latent heat of water vapor											1,039.83
Correction for feed, water excreta, and vessels											− 17.80
Total heat											5,683.14

TABLE XI.—*Heat measurements*—Continued.

Period.	Relative rate of flow.	Average temperature of water current.					Total water.	Average specific heat of water.	Heat produced in absorbers.		Total heat, calories at 20°.
		Ingoing.	Outcoming.	Difference.	Correction for pressure.	Corrected difference.			Difference of pressure.	Equivalent heat.	
PERIOD III*b*—Cont'd.											
Subperiod 2.		°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	*Liters.*		*Cm.*	*Cal.*	
6 a. m. to 10.33 a. m....	36.0	2.4933	4.5211	2.0278	0.0050	2.0328	839.00	1.0066	3.00	0.80	1,715.98
10.33 a. m. to 11.34 a. m.	31.0	3.0787	5.7440	2.6653	.0012	2.6665	106.00	1.0060	.75	.03	284.32
11.34 a. m. to 12.25 p. m.	30.0	3.1423	6.2508	3.1085	.0010	3.1095	76.00	1.0058	.50	.01	237.68
12.25 p. m. to 12.33 p. m.	29.0	3.2250	6.7150	3.4900	.0008	3.4908	8.50	1.0057	.40	......	29.84
12.33 p. m. to 1.47 p. m..	34.0	2.7544	5.1600	2.4056	.0032	2.4088	190.50	1.0063	2.00	.12	461.65
1.47 p. m. to 1.54 p. m..	33.0	2.7450	4.9400	2.1950	.0024	2.1974	16.00	1.0063	1.50	......	35.38
1.54 p. m. to 2.44 p. m..	29.0	3.1108	6.8450	3.7342	.0008	3.7350	57.50	1.0057	.40	......	215.99
2.44 p. m. to 6 p. m....	33.0	2.7171	5.4371	2.7200	.0024	2.7224	458.50	1.0062	1.50	.22	1,255.74
											4,236.58
Latent heat of water vapor..............	....										960.73
Correction for feed, water, excreta, and vessels..............	....										−82.25
Total heat.......	....										5,115.06
Subperiod 3.											
6 p. m. to 8.07 p. m......	33.0	2.7809	5.5312	2.7503	.0024	2.7527	293.00	1.0062	1.50	.14	811.40
8.07 p. m. to 9.30 p. m ..	29.0	3.2067	7.3129	4.1062	.0008	4.1070	95.50	1.0055	.40	.01	394.36
9.30 p. m. to 9.36 p. m ..	33.0	2.8800	6.1000	3.2200	.0024	3.2224	11.50	1.0060	1.50	......	37.28
9.36 p. m. to 10.02 p. m..	35.0	2.7743	5.3029	2.5286	.0040	2.5326	73.50	1.0062	2.50	.06	187.24
10.02 p. m. to 1.25 a. m..	37.0	2.8249	4.9000	2.0751	.0062	2.0813	663.00	1.0063	3.50	.74	1,387.85
1.25 a. m. to 2.58 a. m...	32.0	3.2100	5.9000	2.6900	.0020	2.6920	178.50	1.0059	1.00	.06	483.30
2.58 a. m. to 3.14 a. m...	35.0	3.0925	5.4850	2.3925	.0040	2.3965	47.50	1.0061	2.50	.04	114.48
3.14 a. m. to 3.47 a. m...	37.0	2.8613	5.0451	2.1838	.0062	2.1900	90.00	1.0063	3.50	.10	198.24
3.47 a. m. to 5.14 a. m...	32.0	2.6382	5.3873	2.7491	.0020	2.7510	169.50	1.0063	1.00	.05	469.18
5.14 a. m. to 5.27 a. m...	30.0	2.4400	5.9600	3.5200	.0010	3.5210	7.00	1.0062	.50	......	24.80
5.27 a. m. to 5.44 a. m...	28.0	2.7725	7.7125	4.9400	.0006	4.9406	23.00	1.0056	.30	......	114.27
5.44 a. m. to 6 a. m.....	35.0	2.0300	5.2225	3.1925	.0040	3.1965	43.25	1.0065	2.50	.03	139.12
											4,361.52
Latent heat of water vapor..............	....										1,002.44
Correction for feed, water, excreta, and vessels..............	....										−18.85
Total heat.......	....										5,345.11
Subperiod 4.											
6 a. m. to 9.04 a. m.....	37.0	1.9639	4.1550	2.1911	.0062	2.1973	575.50	1.0069	3.50	.64	1,272.63
9.04 a. m. to 9.18 a. m ..	36.0	2.1700	4.1975	2.0275	.0050	2.0325	40.50	1.0068	3.00	.04	82.83
9.18 a. m. to 11.28 a. m .	29.0	3.0169	7.1572	4.1403	.0008	4.1411	138.00	1.0056	.40	.02	574.65
11.28 a. m. to 1.43 p. m..	36.0	2.6065	4.9512	2.3447	.0050	2.3497	392.50	1.0064	3.00	.37	927.79
1.43 p. m. to 1.45 p. m...	29.0	2.6600	5.0300	2.3700	.0008	2.3708	1.00	1.0064	.40	......	2.38
1.45 p. m. to 6 p. m....	36.0	2.8551	5.0764	2.2213	.0050	2.2263	731.50	1.0063	3.00	.70	1,638.09
											4,498.37
Latent heat of water vapor..............	....										1,096.07
Correction for feed, water, excreta, and vessels..............	....										−32.73
Total heat.......	....										5,561.71

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Issued January 18, 1908.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 102.

A. D. MELVIN, CHIEF OF BUREAU.

FURTHER EXPERIMENTS CONCERNING THE PRODUCTION OF IMMUNITY FROM HOG CHOLERA.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., September 25, 1907.

Sir: I have the honor to transmit herewith a paper entitled "Further Experiments Concerning the Production of Immunity from Hog Cholera," by Doctors M. Dorset, C. N. McBryde, and W. B. Niles, of the Biochemic Division of this Bureau, and to recommend its publication as a bulletin in the Bureau series.

This paper embodies the records of experiments carried out during the seasons of 1903, 1904, 1905, and 1906, this work being a continuation of that reported in Bulletin 72 of this Bureau. The results obtained show quite clearly that a comparatively certain method of protecting hogs from hog cholera has been secured. The experiments, however, have not as yet been extensive enough, nor have they been applied under the varying conditions of practice to a sufficient extent to warrant claims concerning the practical value of the methods described in this paper, though it is strongly believed that they should be of great service in combating hog cholera in this country.

Very respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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FURTHER EXPERIMENTS CONCERNING THE PRODUCTION OF IMMUNITY FROM HOG CHOLERA.

INTRODUCTION.

In a previous publication from this Bureau[a] it has been shown that the disease known as hog cholera, encountered in epizootic form in Iowa and other parts of the United States, is caused by a filterable and probably ultramicroscopic virus which exists in the blood of sick hogs, and that *Bacillus choleræ suis,* although present in most cases of hog cholera, in all likelihood plays the part of a secondary invader. This modification of our views regarding the etiology of hog cholera necessarily carried with it changes in plans for combating the disease.

Most of the methods for combating the disease which have heretofore been proposed were very naturally based upon the general belief that *B. choleræ suis* was the cause of hog cholera, and many different methods of preparing vaccines and antitoxic sera through the use of that organism were devised and subjected to extensive laboratory as well as practical tests. Although a certain degree of success was apparently attained in some instances, none of these methods have been found to act with sufficient reliability to warrant their use in practice.

In the case of vaccines prepared from cultures of *B. choleræ suis* a certain amount of immunity against that organism may have been at times induced in the treated hogs, and a similar result may have been secured by the administration of antitoxins prepared through the use of the same organism, for in the earlier publication above referred to it has been shown that *B. choleræ suis* usually invades the body of the hog after injection with the filterable virus, and, as stated there, it is reasonable to believe that the final result of the disease is in many cases materially influenced by the presence of that organism. Any vaccine or serum which protects against *B. choleræ suis* would therefore be expected to aid the body in its struggle against the twofold invasion of filterable virus and *B. choleræ suis.* We believe that the partial success attained at times by the use of sera and vaccines prepared from *B. choleræ suis* is to be explained upon this ground.

In view of the fact, however, that the filterable virus is the primary invader, and that it appears to be quite sufficient in itself to cause the death of most hogs, any substance which protects only from *B. choleræ suis* must necessarily be regarded simply as a palliative, which, in the light of past experiences, is without a value that is in any way commensurate with the cost of applying it.

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[a] Bulletin 72, Bureau of Animal Industry, U. S. Dept. of Agriculture.

It thus seems evident that all efforts looking to the prevention or treatment of hog cholera should be directed primarily toward securing some means of protecting the hog from invasion by the filterable virus, or of overcoming that virus if invasion has already taken place.

Since it was first definitely determined that *B. choleræ suis* is not the primary cause of hog cholera the work of the Bureau of Animal Industry has been along the lines just suggested. Much difficulty has been experienced in carrying out this work, due in great measure to our inability to cultivate the filterable virus artificially and to the fact that of all animals exposed to this virus only hogs have proven susceptible. We have thus been restricted to the use of the blood and tissues of sick hogs in our attempt to secure a satisfactory serum or vaccine.

As stated in Circular 43 of this Bureau, issued February 12, 1904, "the basis of the immunity experiments, therefore, has been the use of attenuated and disease-producing liquid or dried blood, or the use of this blood mixed with blood obtained from immune animals, in which animals the immunity has been increased by the injection of large doses of disease-producing blood obtained from hogs known to have the disease; or, in other words, disease-producing blood and antitoxic blood separate and combined have been successfully used." [a]

The efforts to attenuate the virus in blood from diseased hogs by drying, by heat, and by chemical agents have not led to satisfactory results. This appears to be due in part at least to the unequal resistance of the virus in different lots of diseased blood to these agencies. At times the protection afforded by diseased blood attenuated artificially has appeared to be complete; at others a vaccine prepared in identically the same manner has either caused death, thus showing an entire lack of attenuation, or else the hogs have shown no ill effects from the vaccination but have succumbed promptly when exposed to hog cholera, showing that the supposed vaccine had no protective power whatever.

It may be that later investigations will show that it is possible to obtain a satisfactory vaccine for hog cholera by attenuating the virus, but our own results were so discouraging that efforts in this direction were abandoned and our entire attention turned to the production of a serum in the manner hereinafter described.

---

[a] Subsequent to the publication of Circular 43, Boxmeyer and McClintock (Journal of Infectious Diseases, vol. 2, No. 2, March, 1905), described a few experiments along these lines and seemed to obtain better results by using a combination of disease-producing blood and immune serum than by using an artificially attenuated virus.

PRELIMINARY EXPERIMENTS.

The earlier experiments, which had for their object the production of a serum which would protect from the filterable virus, were not wholly successful, some of them indeed resulting in almost complete failure; but as these failures are quite instructive on account of the light they throw upon the details of producing the serum, it seems desirable to describe them very briefly before taking up the more recent work.

As it was known that immune hogs could withstand perfectly injections of disease-producing blood[a] which were more than sufficient to destroy nonimmunes, the plan originally adopted was to inject hogs immune from hog cholera with disease-producing blood in increasing doses, the object of this treatment being, of course, to impart a protective power to the blood of the immune, previous experiments having shown that blood from nonhyperimmunized immunes possessed very little if any such power. The records of two experiments carried out with serum from immune hog 844 treated in this manner are given below.

EXPERIMENTS OF 1903 AND 1904.

Immune hog 844 was an adult animal weighing approximately 150 pounds, which had recovered from an attack of hog cholera. This immune was injected subcutaneously with increasing doses of disease-producing blood which had been shown to contain the filterable virus.[b]

The amount of disease-producing blood injected was increased to 400 c. c. before blood was drawn from the immune.

The following statement shows the dates and amounts of disease-producing blood used for injection of immune hog 844,[c] with records of blood drawings:

July 24, 1903, 1 c. c. disease-producing blood injected.
August 4, 1903, 4 c. c. disease-producing blood injected.
August 19, 1903, 12 c. c. disease-producing blood injected.
September 1, 1903, 30 c. c. disease-producing blood injected.
September 26, 1903, 50 c. c. disease-producing blood injected.
October 14, 1903, 250 c. c. disease-producing blood injected.
October 20, 1903, 250 c. c. disease-producing blood injected.
October 29, 1903, 400 c. c. disease-producing blood injected.
November 9, 1903, 100 c. c. blood drawn from tail.

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[a] The term "disease-producing blood" is applied in this paper to blood from hogs affected with hog cholera, which blood was shown to be capable of causing the disease when injected into nonimmune hogs.

[b] See experiments with blood from Herd I, Bulletin 72, Bureau of Animal Industry, pp. 43–65.

[c] We acknowledge our indebtedness to Dr. E. C. Schroeder, who had these injections, as well as those described under experiments A and B, made for us at the Experiment Station of this Bureau at Bethesda, Md.

November 19, 1903, 400 c. c. disease-producing blood injected.
December 10, 1903, 480 c. c. disease-producing blood injected.
January 4, 1904, 150 c. c. blood drawn from tail.
January 5, 1904, 490 c. c. disease-producing blood injected.
January 28, 1904, 480 c. c. disease-producing blood injected.
February 9, 1904, 185 c. c. blood drawn from tail.

It is interesting to note that even the largest doses of disease-producing blood did not seriously disturb the general health of the immune, the only ill effects noted after the injection of the blood being swelling at the point of injection and occasionally a temporary loss of appetite.

Two experiments to test the protective value of the blood drawn from hog 844 were carried out.

TABLE 1.—*Experiment A with blood drawn November 9, 1903, from immune hog 844.*

No. of hog.	Material injected.	Inoculation.		Exposure.	
		Date.	Result.	Date.	Result.
1002....	20 c. c. defibrinated blood of hog 844, subcutaneously.	Nov. 11, 1903	Remained well.	Dec. 18, 1903	Died; hog cholera.
1004....	20 c. c. defibrinated blood of hog 844+1 c. c. disease-producing blood.	.....do.......	.....do....	.....do.......	Remained well.
1003....	1 c. c. disease-producing blood..........	.....do.......	Died; hog cholera.	....	

TABLE 2.—*Experiment B with blood drawn February 9, 1904, from immune hog 844.*

No. of hog.	Material injected.	Inoculation.		Exposure.	
		Date.	Result.	Date.	Result.
1086....	20 c. c. blood of hog 844+1 c. c. disease-producing blood.	Feb. 11, 1904	Remained well.	Mar. 11, 1904	Died; hog cholera.
1087....	.....do............................	.....do.......	.....do....	.....do.......	Remained well.
1088....	.....do............................	.....do.......	.....do....	.....do.......	Sick; recovered.
1089....	.....do............................	.....do.......	.....do....	.....do.......	Died; hog cholera.
1090....	1 c. c. disease-producing blood alone...	.....do.......	Died; hog cholera.	....	
1091....	.....do............................	.....do.......	.....do....	....	

Experiment A.—By referring to Table 1 it will be seen that only three hogs were used in this experiment. Of these, after injection, the one that received only immune blood remained well; the one which received both immune blood and disease-producing blood also remained well, while the third animal which received only disease-producing blood died of hog cholera. When the two surviving hogs were injected approximately thirty days later with disease-producing blood to test their immunity the one which had been treated previously with immune blood alone died, while the other which had received the mixture of immune blood and disease-producing blood remained well.

Experiment B. —This experiment was designed as a control on the results of experiment A, except that it was considered unnecessary to use the immune serum alone, as it appeared not to produce any lasting immunity. One point of difference between experiments A and B should be noted: Experiment B was carried out with immune blood drawn February 9, 1904, whereas in experiment A the drawing of November 9, 1903, was used.

The two experiments agree in showing that the serum from the hyperimmunized immune was capable of protecting hogs from hog cholera when the infection took place simultaneously with the administration of the immune serum. It is evident, however, that the duration of the immunity secured by these injections was not of sufficient length to render the method, as used at that time, suitable for practical purposes. Other experiments with blood from immune hog 844 and from other hyperimmunized hogs about the same time did not lead to more promising results, and the experiments were therefore laid aside temporarily on account of the pressure of other work.

EXPERIMENTS OF 1905.

In the spring of 1905 this work was resumed with the intention of determining whether it was possible to secure by means of the above-described method, or some variation of it, an immunity which would be more lasting than that obtained in previous experiments.

Four immunes were used to supply serum. These hogs were all adult animals, more than a year old, and had all passed through exposure to hog cholera without exhibiting noticeable symptoms of disease. It is difficult to classify these hogs as possessing either "natural" immunity or "acquired" immunity, as they may have suffered a light attack of disease which passed by unnoticed. It is quite certain, however, that they possessed considerably greater powers of resistance than is ordinarily the rule in hogs.

Two methods were resorted to for hyperimmunizing these hogs. For the sake of convenience the first plan has been designated the "slow method" and the second the "quick method," depending upon the manner of injecting the disease-producing blood. The slow method consisted of three successive injections of disease-producing blood, followed by a drawing of blood from the immune, and then more injections of disease-producing blood, followed by more drawings from the immune; in other words, it followed in a general way the plan used in raising the potency of the blood serum of immune cattle for securing a protective serum for "rinderpest." The quick method is along the line of Nicolle's so-called "méthode brutale" of producing an antirinderpest serum, and was planned to consist of one very large dose of disease-producing blood administered subcutaneously, and followed after an interval of ten days or more by blood drawings from the immune. It was planned to use a different strain of disease-producing blood for injecting each immune, but this could not be done owing to the impossibility of securing a sufficient quantity of blood from different outbreaks at the time the injections were to be made. All of the immunes, therefore, were injected with diseased blood which might be considered a mixture of several different strains, but which was virulent in all cases (as proven by the injection of controls) unless otherwise stated.

In view of the virulence of this blood the behavior of the immunes after injection seems truly remarkable, for not one of them showed any ill effects whatever other than a transitory stiffness, due undoubtedly to the local inflammation caused by the large injections. Immune hog Q No. 2 received 1,440 times the usual lethal dose of hog-cholera blood without any effect whatever being noticeable except a little stiffness. As far as the immune is concerned, therefore, there seemed to be no reason why the single large dose should not be used instead of the much slower process of administering the disease-producing blood in increasing doses.

IMMUNES USED FOR PRODUCTION OF SERUM IN 1905.

A very brief history of each of the immunes is given below. It should be noted that the virulence of the disease-producing blood injected was tested each time by the injection of one or more non-immune hogs, and in each case it proved to be of high pathogenic power unless otherwise stated.

Hyperimmunized Immune Q No. 1 (Quick Method).

This hog passed through an exposure to hog cholera in the summer of 1904 without showing any symptoms of disease, and was not subjected to further exposure until the summer of 1905, when it weighed approximately 130 pounds. On September 12, 1905, it was injected subcutaneously with 900 c. c. of blood that was supposed to be virulent, but nonimmune hogs that were given small doses of the same blood did not sicken, so the treatment had to be repeated. On October 16, 1905, this hog was given 1,275 c. c. of virulent blood. No reaction worthy of note followed this injection. Blood drawings from this immune were made as follows:

November 1, 1905, 140 c. c. defibrinated blood obtained.
November 9, 1905, 125 c. c. defibrinated blood obtained.
November 16, 1905, 150 c. c. defibrinated blood obtained.
December 27, 1905, 200 c. c. defibrinated blood obtained.

The first drawing of this blood was used in the vaccination of hogs in the 1905 experiment.

Hyperimmunized Immune Q No. 2 (Quick Method).

This hog passed through an exposure to hog cholera in 1904 without showing any symptoms of disease. On November 1, 1905, when the hog weighed 145 pounds, it was injected subcutaneously with 1,440 c. c. of disease-producing blood. Some soreness and stiffness followed this injection, but otherwise the animal remained well.

Drawings of blood were made from hog Q No. 2 as follows:

November 24, 1905, 225 c. c. of defibrinated blood obtained.
December 1, 1905, 230 c. c. of defibrinated blood obtained.
December 8, 1905, 200 c. c. of defibrinated blood obtained.
December 27, 1905, 350 c. c. of defibrinated blood obtained.

The first drawing of blood from this hog was used in the vaccination of hogs in the 1905 experiments, and the second drawing was used in the 1906 experiment to test the keeping quality of immune serum.

HYPERIMMUNIZED IMMUNE 1234 (SLOW METHOD).

This hog was first exposed to hog cholera on November 9, 1904, when it was placed in a pen with sick hogs; no illness resulted. On September 29, 1905, at which time it weighed 168 pounds, hog 1234 was injected subcutaneously with 175 c. c. of disease-producing blood. This was followed on October 21 by 420 c. c. of disease-producing blood, and the third dose, 840 c. c., was given November 5, 1905. About two months later, or, to be exact, on January 13, 1906, the hog received the last dose of disease-producing blood. The virulence of the blood used for each of these injections was proven by the production of disease in nonimmune hogs. Drawings of blood were made from the tail of this hog as follows:

November 14, 1905, 100 c. c. defibrinated blood obtained.
November 21, 1905, 130 c. c. defibrinated blood obtained.
November 28, 1905, 125 c. c. defibrinated blood obtained.
January 24, 1906, 450 c. c. defibrinated blood obtained.
February 2, 1905, 525 c. c. defibrinated blood obtained.
August 31, 1906, 60 c. c. defibrinated blood obtained.

The first drawing of serum from hog 1234 was used in the 1905 experiments, while the second drawing and last drawing were used in 1906 Experiments XXVIII and XXIX, hereinafter described.

HYPERIMMUNIZED IMMUNE 1212 (SLOW METHOD).

Hog 1212 was injected with blood from a sick hog on August 27, 1904, and was later placed in the exposure pen, but in neither instance did the hog become sick.

On September 29, 1905, this immune weighed approximately 160 pounds and was injected with 175 c. c. of disease-producing blood. The injection of disease-producing blood was repeated as follows:

October 21, 1905, 420 c. c.
November 5, 1905, 820 c. c.
January 13, 1906, 840 c. c.

Practically no symptoms followed these injections, although nonimmunes that received only 5 c. c. of the same blood contracted hog cholera and in most instances died.

Drawings of blood were made from immune hog 1212 as follows:

November 14, 1905, 100 c. c. defibrinated blood obtained.
November 21, 1905, 140 c. c. defibrinated blood obtained.
November 28, 1905, 10 c. c. defibrinated blood obtained.
January 24, 1906, 75 c. c. defibrinated blood obtained.

The first drawing of this serum was the only one used for experimental purposes, and this was used in the 1905 experiments only.

VACCINATION EXPERIMENTS IN 1905.

Only the first drawings of hyperimmune blood were used in the experiments described below. The blood was defibrinated, separated from the clot, and mixed with sufficient 5 per cent carbolic acid solution to give a 0.5 per cent solution in the defibrinated blood.

In so far as the method of vaccination is concerned, the 1905 experiments practically repeat those of 1903 and 1904, though of course the mode of hyperimmunizing the immunes was modified as explained above. It was also hoped to determine whether different immunes varied in their power to yield a potent serum, whether the "quick" or the "slow" method of hyperimmunization was preferable, and whether by increasing the amount of disease-producing blood given to the immunes the duration of the immunity in treated hogs could be prolonged. The amount of disease-producing blood administered with the immune blood for the purposes of vaccination was also varied for similar reasons. In all treated hogs the diseased blood and the hyperimmune serum were injected simultaneously on different sides of the body beneath the skin. Control animals of the same size and age, and of the same litters also, if available, were injected with the same dose of the same disease-producing blood alone in order to demonstrate the protective value of the immune blood.

Several weeks after vaccination the hogs which withstood the treatment were placed in an "exposure pen."[a] This pen contained hogs sick of hog cholera, and as the pen was comparatively small the exposure to which the treated hogs were subjected was quite as severe as any that could be encountered under natural conditions by association. The severity of this exposure is made plain by the death of the control animals.

It seems unnecessary to give detailed records of the hogs used in this and succeeding experiments. It may be stated, however, that in cases where hogs became sick the clinical records and the autopsy findings in all cases were such as are usually met with in hog cholera, unless otherwise stated. The salient features are set down in Table 3.

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[a] The term "exposure pen" as used in this paper refers to a pen where hogs sick of hog cholera were kept and hogs placed therein were subjected at all times to close association with the sick animals. The exposure was entirely by association, as the hogs were not allowed to feed upon the bodies of those that died.

TABLE 3.—*Results of hog vaccinations in experiments of 1905.*

No. of hog.	Weight.	Material injected.	Inoculation.		Exposure.		Autopsy.
			Date.	Result.	Date.	Result.	
	Pounds.						
1397	60	10 c. c. first drawing of serum from hog Q No. 1; 1 c. c. disease-producing blood of hog 1394.	Dec. 2, 1905	Sick; recovered	Dec. 27, 1905	Remained well	
1398	60	20 c. c. first drawing of serum from hog Q No. 1; 1 c. c. disease-producing blood of hog 1394.	do	do	do	do	
1422	50	10 c. c. first drawing of serum from hog Q No. 1; 2 c. c. disease-producing blood of hog 1406.	Dec. 16, 1905	Died Dec. 29, 1905			Engorged spleen, etc.
1423	50	20 c. c. first drawing of serum from hog Q No. 1; 2 c. c. disease-producing blood of hog 1406.	do	Died Jan. 22, 1906			Ulcers.
1399	60	10 c. c. first drawing of serum from hog Q No. 2; 1 c. c. disease-producing blood of hog 1394.	Dec. 2, 1905	Remained well	Dec. 27, 1905	Remained well	
1400	60	20 c. c. first drawing of serum from hog Q No. 2; 1 c. c. disease-producing blood of hog 1394.	do	do	do	do	
1424	45	10 c. c. first drawing of serum from hog Q No. 2; 2 c. c. disease-producing blood of hog 1406.	Dec. 16, 1905	do	Jan. 9, 1906	do	
1425	45	20 c. c. first drawing of serum from hog Q No. 2; 2 c. c. disease-producing blood of hog 1406.	do	do	do	do	
1401	60	10 c. c. first drawing of serum from hog 1234; 1 c. c. disease-producing blood of hog 1394.	Dec. 2, 1905	do	Dec. 27, 1905	do	
1402	60	20 c. c. first drawing of serum from hog 1234; 1 c. c. disease-producing blood of hog 1394.	do	do	do	do	
1426	50	10 c. c. first drawing of serum from hog 1234; 2 c. c. disease-producing blood of hog 1406.	Dec. 16, 1905	do	Jan. 9, 1906	do	
1427	50	20 c. c. first drawing of serum from hog 1234; 2 c. c. disease-producing blood of hog 1406.	do	do	do	do	
1403	60	10 c. c. first drawing of serum from hog 1212; 1 c. c. disease-producing blood of hog 1394.	Dec. 2, 1905	do	Dec. 27, 1905	do	
1404	60	20 c. c. first drawing of serum from hog 1212; 1 c. c. disease-producing blood of hog 1394.	do	do	do	do	

TABLE 3.—*Results of hog vaccinations in experiments of 1905*—Continued.

No. of hog.	Weight.	Material injected.	Inoculation.		Exposure.		Autopsy.
			Date.	Result.	Date.	Result.	
	Pounds.						
1428	50	10 c. c. first drawing of serum from hog 1212; 2 c. c. disease-producing blood of hog 1406.	Dec. 16, 1905	Remained well	Jan. 9, 1906	Remained well	
1429	50	20 c. c. first drawing of serum from hog 1212; 2 c. c. disease-producing blood of hog 1406.	do	do	do	do	
1405	60	1 c. c. disease-producing blood of hog 1394.	Dec. 2, 1905	Sick Dec. 7; died Dec. 12, 1905.			Hemorrhagic lesions.
1406	60	do	do	Sick Dec. 7; killed Dec. 15, 1905.			Do.
1407	60	do	do	Sick Dec. 7, 1905; died Feb. 7, 1906.			Ulcers.
1408	60	do	do	Sick; recovered			
1430	50	2 c. c. disease-producing blood of hog 1406	Dec. 16, 1905	Died Jan. 3, 1906			Hemorrhagic lesions.
1431	50	do	do	Died Jan. 4, 1906			Hemorrhages and ulcers.
1432	50	do	do	Died Jan. 11, 1906			Do.
1433	50	do	do	Died Jan. 12, 1906			Do.
1409	60	Check in exposure pen			Dec. 27, 1905	Died Feb. 10, 1906	Do.
1410	60	do			do	Remained well	
1411	60	do			do	Very sick; killed	Do.
1412	60	do			do	do	Do.
1455	35	do			Jan. 8, 1906	Died Jan. 17, 1906	Do.
1456	40	do			do	Died Jan. 20, 1906	Do.
1457	40	do			do	Remained well	

As will be seen from Table 3, 16 hogs were vaccinated by the use of a combination of hyperimmune blood and disease-producing blood, blood from each immune serving for the treatment of 4 hogs in doses of 10 c. c. and 20 c. c. Half of the treated hogs received 2 c. c. of disease-producing blood and the remainder 1 c. c., simultaneously with the immune blood. For the purpose of control, 8 hogs were injected with disease-producing blood alone, half of these receiving 2 c. c. and the remainder 1 c. c., all injections being made subcutaneously.

Of the 16 hogs which were vaccinated, 2 died, 2 became sick but recovered, and 12 showed no symptoms of illness whatever as a result of the treatment. The animals which became sick were all treated with serum from immune hog Q No. 1, the serum from this immune appearing to be barely sufficient to protect from 1 c. c. of disease-producing blood, but not potent enough to protect from 2 c. c. Serum from the other 3 immunes gave perfect protection from 2 c. c. as well as from 1 c. c. of disease-producing blood when injected simultaneously with it, and the protection afforded by 10 c. c. of this serum seemed to be quite as satisfactory as that secured by the use of twice that amount.

The protective power of the serum from hyperimmunized hogs Q No. 2, 1234, and 1212 is made strikingly apparent by the behavior of the control animals, which were injected with disease-producing blood alone. Of the 8 hogs thus injected, 6 died of hog cholera, 1 was killed when in a moribund condition, and the eighth hog also contracted the disease but recovered. From these facts there seems to be no reason for doubting the protective power of the serum from these 3 immunes when injected simultaneously with disease-producing blood.

In order to determine whether or not this immunity was of more than fleeting duration the survivors from the vaccinating dose were placed in the exposure pen together with 7 untreated healthy hogs, as shown in Table 3. This exposure to disease by association took place twenty-four days after vaccination in the case of 6 of the treated hogs and twenty-five days after the vaccination of the remaining 8 hogs. The interval between vaccination and exposure was not as long as was desired, but owing to the lateness of the season it was considered best to expose at that time rather than wait until the following summer.

It will be seen from the table that not one of the vaccinated hogs contracted disease as a result of this exposure. Of the 7 control hogs which were placed in the exposure pen at the same time as the vaccinated hogs to prove the virulence of the exposure, 5 contracted hog cholera, while 2 remained well. Of the 5 which contracted the disease, 3 died and 2 were killed when desperately sick to secure blood for other experiments.

From the results given above there seems to be no reason to doubt the power of serum from hyperimmunized immunes to protect nonimmunes from a fatal dose of disease-producing blood administered simultaneously with the hyperimmune serum. It appears also that in the case of serum from 3 of the immunes, at least, a dose of 10 c. c. was quite as effective as 20 c. c. The serum from both immunes which were hyperimmunized by the slow method proved potent, whereas serum from immune hog Q No. 1 treated by the quick method failed to give satisfactory results. The low protective power of the serum from this immune would appear to be due to some peculiarity on the part of the immune itself, inasmuch as blood from immune hog Q No. 2 treated by the same method proved quite as effective as blood from either of the "slow" immunes. Without more extended trials, therefore, with other immunes, preference could not be given to either one of the methods of hyperimmunization over the other. These experiments indicate also that large doses of disease-producing blood may be expected to confer upon the blood of the immune the power to protect nonimmunes for a greater length of time than blood from immunes which receive considerably smaller doses, for in the experiments carried out up to this time the immunity exhibited by the vaccinated hogs after treatment may have been due (in some of the treated hogs at least) to the action of the immune blood alone and not necessarily to the combined action of immune and disease-producing blood.

It will be remembered that in the experiments of 1903 and 1904 the immune blood protected the treated animals from the disease-producing blood which was administered simultaneously with it, but some of the vaccinated animals succumbed when exposed to hog cholera about thirty days later. The most rational explanation of this occurrence appeared to lie in the supposition that too much immune blood was administered with the diseased blood. The animals would thus be completely protected from the simultaneous injection of the virus, but owing to this complete protection from the virus the animal body would have no stimulus to bring about a reaction and a consequent production of an active immunity which was aimed at by the simultaneous method of vaccination. Under such circumstances it seemed reasonable to suppose that the vaccinated hogs possessed only a passive and transitory immunity, such as might be expected from the injection of an antitoxin.

In the experiments of 1905 we were unable to clear up this point, owing to difficulties experienced in securing suitable material for the work. The experiments were greatly delayed and it was only possible to carry out those which have just been described. Inasmuch as no hogs were injected with the immune serum alone in these experiments, the question as to the nature of the immunity afforded by our injections could not be definitely determined. There is reason to believe, however, that this may have been due to the serum alone, at least in the case of those which received 20 c. c. of immune serum, while there can be no doubt that the 2 hogs 1397 and 1398, which became sick but recovered, secured an active immunity. It is entirely possible that the other hogs which received 10 c. c. of immune blood with the disease-producing blood suffered a very mild attack of disease and thus secured an active, permanent immunity. It would be natural to suppose, however, that if 10 c. c. of immune serum gave sufficient protection from the disease-producing blood to prevent any outward manifestation of disease the protection afforded by 20 c. c. would be complete, and that subsequent immunity in these hogs would presumably be due to the immune blood alone.

EXPERIMENTS OF 1906.

The experiments thus far described show quite clearly that blood from certain hyperimmunized immunes possesses the power to protect nonimmune hogs from a fatal dose of disease-producing blood administered simultaneously with the serum. It has also been shown that hogs which survive a simultaneous injection of serum and disease-producing blood are rendered immune for at least twenty-five days thereafter, even though they show no reaction after the injection. Notwithstanding the success which attended most of these experiments, many questions affecting the practicability of this method for combating hog cholera yet remained undetermined. In conducting the experiments during the year 1906, therefore, we have endeavored to decide, in so far as time and material would permit, these other questions in connection with experiments designed to substantiate the results already obtained.

PLAN OF THE EXPERIMENTS.

The experiments which are to be described hereafter will perhaps be best understood by indicating the general plan which was followed. The questions to be decided concerned first, the immunes, and second, the hogs that were to be vaccinated.

Questions concerning the immunes.—Without attempting to go into the plans in detail, the 1906 experiments may be said to have had the following objects in view: To determine (1) whether natural immunes or those which have acquired immunity are best suited for serum production; (2) what percentage of either natural or acquired immunes may be expected to yield a potent serum; (3) whether the "quick method" or the "slow method" of hyperimmunization yields the best results; (4) whether disease-producing blood from different outbreaks of hog cholera is equally well suited for the purposes of hyperimmunization; (5) whether the amounts of disease-producing blood used for hyperimmunization might be reduced without affecting the potency of the serum, and (6) how long after the last injection with disease-producing blood the immunes retain the power to furnish a potent serum.

Questions concerning vaccination.—Many questions arise in connection with the practical application of the serum, but it has not thus far been possible to attempt to answer all of them. The principal points we had in mind during the 1906 experiments were as follows: To determine (1) the dose of serum required to protect a small hog (25 to 50 pounds) from a simultaneous injection of a fatal dose of disease-producing blood; (2) the duration of the immunity which follows this simultaneous injection; (3) whether it is necessary to produce a reaction (i. e., visible illness or fever, or both) in order to secure a lasting immunity; (4) whether the administration of sufficient serum to prevent a reaction will tend to shorten the duration of the immunity in vaccinated hogs; (5) whether hogs vaccinated by a simultaneous injection of serum and disease-producing blood are likely to be injured or stunted in growth; (6) whether hogs vaccinated by this "serum-simultaneous" method may communicate hog cholera to unvaccinated hogs by association with them; (7) whether a lasting immunity may be produced by the injection of the serum alone; (8) whether the serum alone can be used successfully as a cure; (9) how long the serum will retain its potency, and (10) whether satisfactory results may be obtained by vaccinating suckling pigs.

GENERAL PLAN FOR THE PRODUCTION OF SERUM IN 1906.

The immunes used.—Eight immune hogs were to be hyperimmunized. If possible, 4 of these were to be hogs that had acquired immunity, while the remainder were to be natural immunes. Four of these 8 hogs (2 natural immunes and 2 that possessed acquired immunity) were to be hyperimmunized by the use of one strain of disease, while the remaining 4 were to be given disease-producing blood from an entirely different source.

Method of hyperimmunization.—There were certain general features in the process of immunization which applied alike to all immunes treated by the same method. First of all, in order to make sure of a firm immunity and to avoid losses later, a preliminary injection of 20 c. c. of disease-producing blood was given each immune. After this the regular process of hyperimmunization was begun. Four of the immunes were hyperimmunized by the quick method and 4 by the slow method described under the 1905 experiments.

The immunes treated by the quick method were injected with one dose of disease-producing blood, the amount administered being equal to 1,000 c. c. of disease-producing blood to each 100 pounds of body weight. Exactly three weeks after this injection blood was drawn from the tails of these immunes and preserved for experimental use. This blood drawing from the immunes was repeated at intervals of seven or eight days until three drawings had been made, and in most cases, as shown by the detailed records which follow, a fourth drawing was made approximately a month after the third drawing.

The immunes treated by the slow method were injected three times. The first dose was in the proportion of 100 c. c. of disease-producing blood to 100 pounds of body weight; the second dose, which followed the first after from ten to fourteen days, was in the proportion of 250 c. c. per 100 pounds body weight, and the third and last dose, which was given approximately twelve days after the second, was in the proportion of 500 c. c. per 100 pounds of body weight. Blood drawings from the immunes hyperimmunized by the slow method were begun nine or ten days after the last injection of disease-producing blood and repeated at intervals of seven days.

The object of these repeated blood drawings from the immunes was of course to secure blood for the purpose of ascertaining how long after the last injection of disease-producing blood the immune retained the power to furnish potent serum. These different drawings of immune blood—that is, some of them—were tested on non-immune hogs, as shown in the experiments hereinafter described.

Method of collecting and preserving the immune blood.—The immune blood was drawn in all cases from the tails of the immunes and was collected in a wide, sterilized dish. It was allowed to coagulate, and the clot which formed was then subjected to pressure in order that all of the serum might be separated from it. Instead of a clear serum, therefore, we secured always a serum containing large numbers of red blood corpuscles and which might be more properly called defibrinated blood. The time required for the red cells to settle and the very considerable loss of serum which would have resulted if we had attempted to use clear serum only, owing to lack of facilities for using a large centrifuge, made it necessary to employ the serum containing red cells. In applying a similar method to cattle the use of a serum containing red cells would no doubt be considered objectionable, owing to the danger of transmitting some intercurrent disease, such as Texas fever, through such injections. Such contingencies were not likely to occur in the case of hogs, however, and, furthermore, any possible danger of this kind was no doubt avoided through the addition of an antiseptic to the serum immediately after it was drawn. After the serum had been completely separated from the clot by pressure and by straining through a sterilized cloth it was mixed with a 5 per cent aqueous solution of carbolic acid in the proportion of 9 parts of serum to 1 of carbolic-acid solution, thus giving a 0.5 per cent solution of carbolic acid in the serum. This served to keep the serum perfectly, provided it was placed at once in sterilized bottles until used. It should be remembered that all of the hyperimmune serum used in the experiments described hereafter consisted, in reality, of 1 part of carbolic-acid solution and 9 parts of serum and red cells.

Sources of disease-producing blood with details of the hyperimmunization.—As already stated, disease-producing blood from two entirely distinct sources was used for the treatment of the immunes. One of these strains of disease was obtained near Scribner, Nebr., and is referred to as the "Scribner disease." The other strain of disease was secured near Alexandria, Va., and has been designated the "Syphax disease." Blood from both of these sources proved quite virulent when administered to nonimmune hogs; the blood from the Scribner outbreak, however, appeared to produce a somewhat more acute type of disease than the blood from the Syphax outbreak. The immunes hyperimmunized with blood from the Scribner outbreak are designated "Scribner immunes," and, depending upon the method used for hyperimmunization, the individuals have been called "Scribner quick immunes" or "Scribner slow immunes," as the case might be. The same plan is followed in speaking of the "Syphax immunes."

DESCRIPTION OF THE SCRIBNER OUTBREAK.

This outbreak of hog cholera occurred near Scribner, Nebr., in the fall of 1905. When this locality was first visited by one of us it was found that hog cholera of a virulent type existed on some half dozen farms. Several of these were visited and the sick animals were found to exhibit the usual symptoms of hog cholera, and at autopsy the usual lesions, such as intestinal ulcers and ecchymoses in the various organs, were noted. From one of these infected herds, in which the final loss was about 74 per cent, blood was secured for experimental purposes. This blood was collected in a sterile vessel, defibrinated, and kept on ice until it was used at the Bureau experiment farm near Ames, Iowa, for the injection of hogs 1395, 1393, and 1394, which received, respectively, 1 c. c., 2.5 c. c., and 5 c. c., subcutaneously on November 18, 1905. These hogs became sick six days after injection, and hogs 1393 and 1395 died on December 3, 1905. The other hog, 1394, was killed on December 1 to secure blood for other experiments. Autopsies which were held on 2 of these hogs revealed the usual lesions of hog cholera.

The blood of hog 1394, after dilution, was filtered through a Chamberland bougie, and the filtered blood was proven to possess the same degree of virulence as the unfiltered blood.

A portion of the unfiltered blood of hog 1394 was placed in sealed glass bulbs and preserved on ice until May, 1906, when, upon injection, it proved to be quite virulent, and hogs inoculated with this disease or exposed to it furnished all of the blood used in hyperimmunizing the so-called "Scribner immunes."

SCRIBNER IMMUNES.

HYPERIMMUNIZED IMMUNE 1286 (QUICK METHOD).

This hog was exposed to hog cholera on August 17, 1905, together with another of about the same weight (50 pounds). As a result of this exposure hog 1286 exhibited only slight indications of sickness and soon recovered, although the other hog exposed at the same time died, showing at autopsy the usual lesions of hog cholera. In order to test further the immunity of hog 1286 it was placed in the station exposure pen where a number of sick hogs were kept. This hog failed to show symptoms of disease and was not exposed further until the summer of 1906, when it weighed 125 pounds.

June 13, 1906, hog 1286 received subcutaneously 20 c. c. of Scribner disease-producing blood, and at the same time a control hog was injected with 10 c. c of the same blood. The control died, while hog 1286 remained well.

June 25, 1906, hog 1286 was injected subcutaneously with 1,250 c. c. of Scribner disease-producing blood secured from several hogs. At the same time 5 nonimmune hogs were injected to serve as checks on the virulence and also to furnish blood for treating other immunes. All of these checks became very sick and were destroyed, while hog 1286 remained well except for slight soreness following the injection.

Blood was drawn from the tail of hog 1286 as follows:

July 16, 1906, 356 c. c. defibrinated blood obtained.
July 23, 1906, 300 c. c. defibrinated blood obtained.
July 30, 1906, 250 c. c. defibrinated blood obtained.

This blood was used in Experiments I and II described in another part of this paper.

HYPERIMMUNIZED IMMUNE 1313 (QUICK METHOD).

This hog was injected subcutaneously with 25 c. c. of diluted diseased blood on September 30, 1905. Hog 1313 did not become noticeably sick as a result of the injection, although the blood was of a fair degree of virulence. A later exposure to disease in the exposure pen was likewise without effect upon this hog. No further exposure to hog cholera was made until the summer of 1906, as described below.

June 13, 1906, hog 1313 received subcutaneously 20 c. c. of Scribner disease-producing blood; a nonimmune hog received at the same time 10 c. c. of the same blood. The check died of hog cholera, but hog 1313 remained well.

July 5, 1906, hog 1313, which weighed 130 pounds, was injected subcutaneously with 1,300 c. c. of Scribner disease-producing blood. Two nonimmune hogs injected at the same time with 2 c. c. each of the same disease-producing blood became very sick and were killed to furnish blood for the other experiments. Hog 1313 was a little sore on the day following the injection; this soon passed away, but on July 8 and for several days thereafter the hog was quite sluggish and disinclined to eat. By July 13, however, recovery was complete. Blood was drawn from the tail of hog 1313 as follows:

July 26, 1906, 400 c. c. defibrinated blood obtained.
August 2, 1906, 465 c. c. defibrinated blood obtained.
August 9, 1906, 450 c. c. defibrinated blood obtained.
September 6, 1906, 400 c. c. defibrinated blood obtained.

The blood from this immune was used in Experiments III and IV, which are described in the following pages:

HYPERIMMUNIZED IMMUNE 1383 (SLOW METHOD).

This hog was injected subcutaneously on November 17, 1905, with 5 c. c. of blood from a hog sick of hog cholera. This blood as a result of a number of inoculations was found to cause the death of somewhat more than 50 per cent of the inoculated hogs. Hog 1383 showed slight sickness after injection, but soon recovered and also remained well when placed in the exposure pen about three weeks later. In June, 1906, this hog was used for the production of serum, as described below.

June 13, 1906, hog 1383 was injected subcutaneously with 20 c. c. of Scribner disease-producing blood. A nonimmune hog was injected at the same time with 10 c. c. of the same blood. The nonimmune died, but hog 1383 remained well.

June 25, 1906, hog 1383 weighed 105 pounds and was injected subcutaneously with 105 c. c. of Scribner disease-producing blood. Five nonimmune hogs injected at the same time with 10 c. c. each of the same blood became very sick and were killed to furnish blood for other experiments; hog 1383 remained well. The blood used for this injection was the same as that used for the hyperimmunization of hog 1286, and the same checks served for both immunes.

July 5, 1906, hog 1383 received a second injection consisting of 265 c. c. of Scribner disease-producing blood. The blood used was the same as that used for the injection of immune 1313 on the same date, and, as stated previously, produced hog cholera in nonimmune animals in doses of 2 c. c. Hog 1383 was made somewhat sore by the injection, but was well again after two or three days.

July 14, 1906, hog 1383 was given a third injection of Scribner disease-producing blood, 525 c. c. being administered subcutaneously. Two nonimmunes injected with 2 c. c. each of the same blood as controls on the virulence of the blood died of hog cholera. Hog 1383 remained well.

This injection completed the hyperimmunization of hog 1383, and blood drawings were made from this animal as follows:

July 24, 1906, 392 c. c. defibrinated blood obtained.
July 31, 1906, 360 c. c. defibrinated blood obtained.
August 7, 1906, 400 c. c. defibrinated blood obtained.
August 14, 1906, 360 c. c. defibrinated blood obtained.
September 4, 1906, 82 c. c. defibrinated blood obtained.

The blood from this immune proved to be exceptionally potent, and it was therefore used in a number of different experiments.

HYPERIMMUNIZED IMMUNE 1403 (SLOW METHOD).

By referring to Table 3 it will be seen that this hog was one of those vaccinated by the serum-simultaneous method in the 1905 experiments. The hog showed no symptoms of disease, either as a result of vaccination or of the subsequent exposure to hog cholera in the exposure pen on December 27, 1905. No further exposure to disease was made until June, 1906, when hyperimmunization was begun. The weight of the hog at this time was 90 pounds.

June 13, 1906, hog 1403 was injected subcutaneously with 20 c. c. of Scribner disease-producing blood. A control injected at the same time with 10 c. c. of the same blood died, whereas hog 1403 remained well.

June 25, 1906, hog 1403 was injected subcutaneously with 90 c. c. of the same disease-producing blood as that used for injecting immunes 1286 and 1383 on the same date. Hog 1403 was not visibly affected by the injection.

July 5, 1906, hog 1403 was injected with 225 c. c. of Scribner disease-producing blood. The same blood was used at the same time for injecting immunes 1313 and 1383 and four control hogs as previously stated. Immune 1403 was sluggish and disinclined to eat for several days following the injection, but by July 9 had apparently recovered.

July 14, 1906, hog 1403 was injected for the last time with 450 c. c. of Scribner disease-producing blood, subcutaneously, blood from the same source being used at the same time for the injection of immune 1383 and two controls, as stated above. Hog 1403 showed about the same disturbance as was noted after the second injection, but was well again in four or five days.

Blood drawings were made from immune 1403 as follows:

July 24, 1906, 395 c. c. defibrinated blood obtained.
July 31, 1906, 390 c. c. defibrinated blood obtained.
August 7, 1906, 400 c. c. defibrinated blood obtained.
August 14, 1906, 360 c. c. defibrinated blood obtained.
September 14, 1906, 360 c. c. defibrinated blood obtained.

DESCRIPTION OF THE SYPHAX OUTBREAK.

This outbreak of hog cholera occurred near Alexandria, Va. At the time the first symptoms of illness were observed, on September 6, 1905, there were 37 hogs in the herd. The disease did not progress very rapidly, but nevertheless all of the hogs were finally attacked by the disease. At the time the herd was first visited by representatives of this Bureau only 9 hogs remained alive, and some of these were killed, while others died, the final result being that 3 hogs out of the 37 that were attacked recovered. The lesions found at autopsy were such as are usually met with in hog cholera, except that the pulmonary lesions in some of the animals were rather more prominent than we have ordinarily found to be the case.

Blood from one of the sick animals in this herd served as the starting point for the strain of disease from which blood was secured to hyperimmunize the "Syphax immunes." Filtered blood from this Syphax herd produced hog cholera when injected into nonimmune hogs, even though it was found to be free from all of the ordinary bacteria.

SYPHAX IMMUNES.

HYPERIMMUNIZED IMMUNE 1392 (QUICK METHOD).

This hog, with 5 others, was injected subcutaneously on November 17, 1905, with 5 c. c. of hog-cholera blood. All became sick as a result of this inoculation and 4 died, hog 1392 and one other finally recovering. Hog 1392 was placed in the exposure pen in December, 1905, and remained well. This hog exhibited quite typical symptoms of hog cholera after the first blood injection, and the immunity subsequently exhibited must be regarded as having been acquired through this attack of disease.

June 13, 1906, hog 1392 received 20 c. c. of virulent Scribner disease-producing blood in common with all of the immunes which were later hyperimmunized with blood from either the Scribner or Syphax outbreaks. Hog 1392 remained well.

July 13, 1906, hog 1392, which at that time weighed 130 pounds, received subcutaneously 1,300 c. c. of Syphax disease-producing blood. Five control hogs which were injected at the same time with 5 c. c. of the same blood became very sick and were killed to furnish blood for other experiments. Hog 1392 was somewhat stiff and sore on the two days following the injection, but otherwise remained well. Drawings of blood from immune 1392 were made as follows:

August 3, 1906, 375 c. c. defibrinated blood obtained.
August 10, 1906, 435 c. c. defibrinated blood obtained.
August 17, 1906, 500 c. c. defibrinated blood obtained.
September 17, 1906, 100 c. c. defibrinated blood obtained.

HYPERIMMUNIZED IMMUNE 1274 (QUICK METHOD).

This hog was first exposed to hog cholera on July 22, 1905, by the subcutaneous injection of 0.25 c. c. of hog-cholera blood. Another hog injected at the same time died, but hog 1274 did not become sick, nor did this hog show symptoms of disease when placed in the exposure pen some weeks later. The records indicate that this hog possessed quite a high degree of natural immunity.

June 13, 1906, hog 1274 was injected subcutaneously with 20 c. c. of Scribner disease-producing blood along with the other immunes. No ill effects were noticed as a result of this inoculation.

July 26, 1906, this hog, which weighed at that time 125 pounds, was injected subcutaneously with 1,250 c. c. of Syphax disease-producing blood, and 4 control hogs were injected at the same time with from 2 c. c. to 5 c. c. each of the same blood. All of the controls became very sick and were killed to furnish blood for other experiments. Hog 1274 showed no marked effects from the injection. Drawings of blood from this hog were made as follows.

August 16, 1906, 450 c. c. defibrinated blood obtained.
August 23, 1906, 450 c. c. defibrinated blood obtained.
September 1, 1906, 378 c. c. defibrinated blood obtained.
October 1, 1906, 700 c. c. defibrinated blood obtained.

HYPERIMMUNIZED IMMUNE 1310 (SLOW METHOD).

This hog, with one other, was injected with hog-cholera blood on September 29, 1905; the mate to hog 1310 showed slight indisposition after the injection, but hog 1310 remained well. Both hogs were later placed in the exposure pen. Hog 1310 did not thrive there, but never became plainly sick. After removal from the exposure pen this hog regained its vigor, and on July 13, 1906, at which time the hyperimmunization was begun, its weight was 180 pounds.

June 13, 1906, the preliminary injection of 20 c. c. of virulent Scribner disease-producing blood was made. No visible reaction followed this injection.

July 13, 1906, hog 1310 was injected subcutaneously with 180 c. c. of Syphax disease-producing blood from the same source as that used for the injection of immune hog 1392 on the same date. Hog 1310 remained well, although the control hogs injected at the same time contracted hog cholera.

July 26, 1906, hog 1310 was injected subcutaneously with 400 c. c. of Syphax disease-producing blood from the same source as that used for the injection of immune hog 1274 on the same date. Hog 1310 showed practically no disturbance of health after this injection, although the control animals injected with a much smaller amount of the disease-producing blood contracted hog cholera.

August 7, 1906, hog 1310 was injected subcutaneously with 900 c. c. of Syphax disease-producing blood. Two nonimmune hogs injected subcutaneously with 2 c. c. and 5 c. c. of the same blood contracted hog cholera and died. With the exception of a little soreness, hog 1310 remained well.

Blood was drawn from this immune as follows:

August 16, 1906, 450 c. c. defibrinated blood obtained.
August 23, 1906, 450 c. c. defibrinated blood obtained.
September 1, 1906, 540 c. c. defibrinated blood obtained.
October 1, 1906, 450 c. c. defibrinated blood obtained.

HYPERIMMUNIZED IMMUNE 1297 (SLOW METHOD).

This hog weighed approximately 55 pounds on September 13, 1905, at which time it was injected subcutaneously with hog-cholera blood. No sickness followed this injection and a later exposure in the exposure pen was likewise without result as far as could be observed, though a mild attack at this time may have passed unobserved.

June 13, 1906, this hog received, with the other immunes, a preliminary injection of 20 c. c. of Scribner disease-producing blood without any symptoms of disease being caused.

June 29, 1906, hog 1297 was injected subcutaneously with 175 c. c. of Syphax disease-producing blood. Two nonimmune hogs injected at the same time with 2 c. c. each of the same blood died of hog cholera. Hog 1297 remained well.

July 13, 1906, hog 1297 was injected subcutaneously with 440 c. c. of Syphax disease-producing blood from the same source as that used for the injection of immunes 1310 and 1392 on the same date. All of the checks injected with the same lot of blood became sick and either died or were killed to furnish blood for other experiments. Hog 1297 remained well except for slight soreness following the injection.

July 26, 1906, hog 1297 was again injected with Syphax disease-producing blood, the dose being 850 c. c. of blood from the same source as that used for the injection of immunes 1274 and 1310 on the same date. As previously stated, controls injected at the same time became sick and were killed to furnish blood for other experiments. Blood was drawn from immune 1294 as follows:

August 4, 1906, 390 c. c. defibrinated blood obtained.
August 11, 1906, 300 c. c. defibrinated blood obtained.
August 18, 1906, 500 c. c. defibrinated blood obtained.
September 17, 1906, 360 c. c. defibrinated blood obtained.

It has been previously stated that it was intended to use, for the production of hyperimmune serum, 4 naturally immune hogs and 4 which had acquired immunity through an attack of hog cholera. When it came to the actual working out of this plan, however, as is shown in the preceding pages, we were only able to secure 1 hog (1392) that had recovered from an undoubted attack of hog cholera; 2 others (1286 and 1383) had shown slight though not characteristic symptoms of that disease, while the fourth (1403), among those that were considered as having acquired immunity, had been vaccinated in 1905, but had not shown symptoms of illness at any time after being vaccinated. In regard to this last-mentioned hog, it should be noted that it has been found to be frequently the case that susceptible hogs may show no symptoms following vaccination and yet may secure through this treatment a firm and lasting immunity, and we believe this to have been the case with hog 1403. The remaining 4 immunes, 1274, 1297, 1310, and 1313, were not vaccinated, but nevertheless they showed no symptoms of disease when exposed to hog cholera, and we may therefore with a reasonable degree of assurance look upon these hogs as being naturally immune. From what has just been said it becomes evident that the plan to test the relative capability of "natural" and "acquired" immunes to produce a potent protective serum could not be carried out on as extensive a scale as was desired, but nevertheless it was hoped that considerable information might be acquired from a comparison of serum from hog 1392 with serum from the hogs that appeared to possess a natural immunity.

VACCINATION EXPERIMENTS IN 1906.

The experiments as originally planned were necessarily modified more or less owing to the existence of conditions which could not be foreseen, but notwithstanding the fact that the original plan was not carried out in all instances it may perhaps lead to a better understanding of the experiments which are now to be described if this plan is briefly outlined.

The experiments with serum from each of the hyperimmunized immunes were to consist of two sections, (1) preliminary experiments and (2) secondary experiments.

Preliminary experiments.—These experiments were designed in the main to determine the potency of the immune serum. A number of nonimmune hogs were to be injected with 2 c. c. each of disease-producing blood. A few of these were to be left untreated as controls, while the others were to receive simultaneously with the disease-producing blood varying doses of the immune serum. Uninoculated hogs were to be placed in the pens with the treated as well as the untreated hogs to determine the likelihood of disease being transmitted by the treated hogs. Any survivors from the preliminary experiments were to be reserved for exposure to hog cholera at a later date.

Secondary experiments.—These were intended to determine many questions of practical interest, the preliminary experiments having already established the degree of potency of the different sera when injected simultaneously with diseased blood. In these secondary experiments four lots of hogs were to be treated.

Lot 1. These hogs were to receive disease-producing blood with the minimum dose of serum required to protect.

Lot 2. These were to receive disease-producing blood with double the minimum amount of serum required to protect.

Lot 3. These were to receive the minimum amount of serum alone.

Lot 4. This lot was to receive the maximum amount of serum alone.

Controls were of course to be injected with disease-producing blood alone, and, as in the preliminary experiments, hogs were to be placed in the pens with the treated as well as the untreated ones to determine the likelihood of disease being conveyed to others by contact. The survivors from these experiments were to be divided into two lots, one to be exposed within thirty days after vaccination, the other to be placed in a quarantine pasture and not subjected to exposure until the expiration of three or more months. As will be explained later, the exposure to hog cholera could not be carried out in the manner planned, owing to an outbreak of disease among the hogs in the quarantine pasture.

In addition to carrying out these preliminary and secondary experiments, serum from certain of the immunes was to be used in special experiments with suckling pigs, and also for the purpose of testing the curative value and the keeping quality of the serum, and other questions of more or less practical importance. Except in the case of these special experiments the tests with the serum from the Syphax and Scribner immunes are described separately.

TESTS OF SERUM FROM HOGS HYPERIMMUNIZED WITH BLOOD FROM THE SCRIBNER OUTBREAK.

The description of the outbreak from which this strain of disease was derived has already been given on page 20, and the history of the immunes with the details of hyperimmunization and time of the various blood drawings has also been given.

Serum from Immune 1286 (Quick Method).

Experiment I.—*Preliminary experiment with first drawing of serum.*

This experiment was carried out in accordance with the plan originally decided upon for all preliminary experiments. Eight hogs were injected; 2 of these received disease-producing blood simultaneously with 5 c. c. of serum, 2 received disease-producing blood with 10 c. c. of serum, 2 disease-producing blood with 15 c. c. of serum, and 2 disease-producing blood alone. These four lots of hogs were placed in separate pens with an uninoculated check in each pen. The hogs which received only 5 c. c. and 10 c. c. of immune serum with the diseased blood became distinctly sick, but recovered; the uninoculated checks in the pens with these did not contract disease, however, in either case; the 2 hogs which received 15 c. c. of immune serum with the disease-producing blood did not become sick, and their pen check also remained well. The 2 hogs which received disease-producing blood alone sickened and died promptly after injection, and at autopsy exhibited the usual lesions of hog cholera; the uninoculated pen check with these last 2 hogs contracted disease from them and showed lesions of hog cholera when destroyed on August 4, 1906.

TABLE 4.—*Preliminary experiment with first drawing of serum from hog 1286 ("quick" immune—Scribner).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1520	30	5 c. c. serum and 2 c. c. disease - producing blood of hog 1505.	July 18, 1906	Sick July 28 to Aug. 12, 1906; recovered.	Oct. 15, 1906	Became unthrifty	Nov. 16, 1906	Died Dec. 8, 1906.	Negative.
1521	40	do	do	do	do	Remained well	do	Became unthrifty and was killed.	Do.
1523	35	10 c. c. serum and 2 c. c. disease - producing blood of hog 1505.	do	Sick July 28 to Aug. 8, 1906; recovered.	do	do	do	Became unthrifty and died Dec. 18, 1906.	Do.
1524	35	do	do	Sick July 28 to Aug. 4, 1906; recovered.	do	do	do	Became unthrifty and died Dec. 10, 1906.	Do.
1526	40	15 c. c. serum and 2 c. c. disease - producing blood of hog 1505.	do	Remained well	do	do	do	Remained well	
1527	35	do	do	do	do	do	do	do	
1522	30	Pen check with hogs 1520 and 1521.		do	do	Sickened and died Nov. 6, 1906.			Hemorrhagic lesions.
1525	40	Pen check with hogs 1523 and 1524.		do	do	do			Do.
1528	30	Pen check with hogs 1526 and 1527.		do		Not exposed			
1529	25	2 c. c. disease-producing blood of hog 1505.	July 18, 1906	Sickened July 26; died Aug. 4, 1906.					Hemorrhages and ulcers.
1530	30	do	do	Sickened July 26; died July 30, 1906.					Do.
1531	30	Pen check with hogs 1529 and 1530.		Sickened Aug. 1; killed Aug. 4.					Hemorrhagic lesions.

The protective power of 1286 serum is well shown by this experiment, in which all the vaccinated hogs survived, while those which received disease-producing blood alone died promptly. It is evident also that 5 c. c. of this serum is probably the least amount that would protect, as even those which received 10 c. c. showed some signs of illness. In accordance with the original plan, the survivors from this experiment were placed in a large quarantine pasture to be reserved for exposure at a later date.

Many other hogs which had been treated in various ways with different sera, together with a considerable number of uninoculated control animals, were placed in this pasture from time to time for the same purpose. In some way hog cholera was accidentally introduced into this pasture toward the end of October, 1906, as shown by the sickness and death of some of the hogs, the autopsies revealing typical lesions of hog cholera. The first hogs to show symptoms of hog cholera in this pasture were the unvaccinated controls about October 15, and the first death among these occurred October 25. This accidental exposure, to which a large number of our vaccinated hogs and unvaccinated control hogs were subjected, resulted in the death of 80 per cent of all the unvaccinated hogs.

Table 4 shows that pen checks 1522 and 1525, which were placed in the quarantine pasture with the vaccinated hogs, both died of hog cholera as a result of this exposure, while none of the vaccinated hogs were made sick. Although this exposure was accidental, it occurred approximately three months after vaccination, and therefore in this instance did not interfere with our plans. As the treated hogs did not become sick from the pasture exposure, they were placed in the exposure pen where hogs sick of hog cholera (Scribner disease) were kept. Conditions in this pen were extremely unfavorable for the general health of the hogs exposed, and the disease was very virulent, as shown by the death of all the check animals. It will be seen from Table 4 that treated hogs 1520, 1521, 1523, and 1524 all became unthrifty. One of these was killed and 3 died about thirty days after being placed in the exposure pen, while 1526 and 1527, the 2 remaining vaccinated hogs, remained well. None of the first 4 hogs mentioned showed any of the lesions of hog cholera at autopsy, and there seems little room to doubt that these hogs died of unthriftiness and impaired vitality caused by the original vaccinating dose. It will be remembered that they became sick after vaccination, and they should therefore have been subsequently much more resistant to hog cholera than the 2 hogs (1526 and 1527) which showed no such symptoms. We consider it quite evident, therefore, that the attack of hog cholera brought on by vaccination weakened the constitution of those which received serum in doses of 5 c. c. and 10 c. c. to such an extent that they could not withstand the unfavorable conditions existing in the exposure pen. The deaths of the checks in the quarantine pasture shows that the pasture exposure was sufficient to cause the death of nonimmune hogs. The fact that all the vaccinated hogs survived shows that when given the same exposure at the end of three months the immunity remained quite firm.

EXPERIMENT II.—*Secondary experiment with first drawing of serum.*

In the secondary experiment with serum from immune 1286 the doses of serum used with disease-producing blood were 10 c. c., which was considered the minimum safe dose, and 20 c. c., double the amount needed to surely protect, as planned. A number of hogs in this experiment were also injected with serum alone. The results which followed vaccination are in complete agreement with those obtained in Experiment I. The 3 hogs injected with disease-producing blood alone contracted hog cholera and died, and the uninoculated hog in this same pen also died of hog cholera contracted from those which received the disease-producing blood alone. Of 6 hogs injected with diseased blood plus 10 c. c. of serum, all became sick and 1 died; the remaining 5 finally recovered. None of the 6 hogs injected with disease-producing blood plus 20 c. c. of immune serum showed any illness after vaccination, and those injected with serum alone likewise remained well. One of the 2 pen checks exposed to the lot of vaccinated hogs which sickened after vaccination contracted hog cholera and was killed; the other remained well.

Nineteen days after vaccination, as shown by Table 5, half of the vaccinated hogs which had received 20 c. c. of serum with disease-producing blood were placed in the Scribner exposure pen. About the same time 2 hogs which had received 20 c. c. of serum alone, 2 which received 10 c. c. of serum alone, and 1 uninoculated pen check were placed in the same exposure pen. Of the hogs which were made sick by vaccination with 10 c. c. of serum plus diseased blood, 3 were placed in the exposure pen thirty-four days after vaccination, together with 1 pen check.

Both of the pen checks (1569 and 1576) which were placed in the exposure pen with the treated hogs died of hog cholera, although not one of the 10 vaccinated hogs showed any visible signs of illness.

As the Scribner strain of disease had been used exclusively for the hyperimmunization of hog 1286, which furnished the serum, and as the diseased blood used in the simultaneous vaccination was of the Scribner strain, and furthermore as the exposure pen in which these hogs were placed to test their immunity contained only the Scribner strain of disease, it was deemed desirable to ascertain the effect of a different strain of disease on the vaccinated hogs. An exposure pen containing only the Syphax strain of disease was therefore prepared, and hogs 1570, 1571, 1573, 1578, 1579, 1582, and 1584 were placed in

TABLE 5.—*Secondary experiment with first drawing of serum from hog 1286 ("quick" immune—Scribner).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1562[a]	40	10 c. c. serum and 2 c. c. disease-producing blood of hog 1531.	Aug. 4, 1906	Slightly sick Aug. 13 to 21, 1906; recovered.			Sept. 7, 1906	Remained well	
1563[a]	55	do	do	do			do	do	
1564[a]	55	do	do	do			do	do	
1565	35	do	do	Slightly sick; recovered.	Oct. 15, 1906	Remained well		Not exposed.	
1566	30	do	do	Slightly sick Aug. 13 to 23, 1906; recovered.	do	do		do	
1567	55	do	do	Sickened Aug. 13; died Aug. 20, 1906.					Hemorrhagic lesions.
1570[a]	35	20 c. c. serum and 2 c. c. disease-producing blood of hog 1531.	do	Remained well			Aug. 23, 1906	Remained well	
1571[a]	40	do	do	do			do	do	
1572	35	do	do	do	Oct. 15, 1906	Remained well	Nov. 19, 1906	do	
1573[a]	50	do	do	do			Aug. 23, 1906	do	
1574	40	do	do	do	Oct. 15, 1906	Remained well	Nov. 16, 1906	do	
1575	65	do	do	do	do	do	Nov. 19, 1906	do	
1578[a]	35	20 c. c. serum alone	do	do			Aug. 21, 1906	do	
1579[a]	40	do	do	do			do	do	
1580	40	do	do	do	Oct. 15, 1906	Sick and died Nov. 7, 1906.			Do.
1581	25	do	do	do	do	Sick and died Nov. 14, 1906.			Do.
1582[a]	35	10 c. c. serum alone	do	do			Aug. 21, 1906	Remained well	
1583	45	do	do	do	Oct. 15, 1906	Killed by other hogs.			No pathological lesions.
1584[a]	40	do	do	do			Aug. 21, 1906	Remained well	
1585	35	do	do	do	Oct. 15, 1906	Unthrifty; died Nov. 14, 1906.			No marked lesions.
1568	55	Pen check with hogs 1562 to 1567.		Sickened Aug. 29; killed Sept. 3, 1906.					Hemorrhagic lesions.
1569	40	do		Remained well			Sept. 7, 1906	Sickened; died Sept. 23, 1906.	Do.
1576	20	Pen check with hogs 1570 to 1575.		do			Aug. 23, 1906	Sickened; died Sept. 15, 1906.	Hemorrhages and ulcers.
1577	35	do		do	Oct. 15, 1906	Sickened; died Nov. 14, 1906.			Do.
1558	20	2 c. c. disease-producing blood of hog 1531.	Aug. 4, 1906	Sickened Aug. 9; died Aug. 16, 1906.					Hemorrhagic lesions.

it about September 15, 1906. On October 30, 1906, the 3 remaining hogs which had withstood exposure in the Scribner exposure pen were also placed in the Syphax exposure pen. None of the vaccinated hogs became sick as a result of this second exposure, although an unprotected hog exposed at the same time contracted hog cholera and died. This would indicate that the serum alone served to confer immunity which might last for six weeks, although the possibility of the immunity being heightened by the exposure in the Scribner exposure pen can not be overlooked.

The remainder of the vaccinated hogs in Experiment II, together with pen check 1577, none of which were exposed in the exposure pen, were placed in the quarantine pasture to await a later exposure. As previously explained, however, our plans in this respect were interfered with by an unforeseen outbreak of hog cholera among the control hogs which were being kept with the vaccinated hogs in this quarantine pasture. This outbreak occurred approximately two and one-half months after vaccination of the hogs in Experiment II. The vaccinated hogs in this experiment which were exposed in this manner consisted of 2 that had received 10 c. c. of serum with 2 c. c. of diseased blood, 3 that had received 20 c. c. of serum with diseased blood, and 2 each of those which received 20 c. c. and 10 c. c. of immune serum alone. (See Table 5.) One of those that had received 10 c. c. of serum alone was killed by other hogs the day it was placed in the pasture. Check hog 1577 died of hog cholera as a result of this exposure. Of the vaccinated hogs, both of those injected with 20 c. c. of serum alone died of hog cholera; the remaining one injected with 10 c. c. of serum alone died, but no marked lesions were found at autopsy. The hogs which were given 10 c. c. and 20 c. c. of serum simultaneously with diseased blood remained well. The 3 hogs vaccinated with 20 c. c. of serum plus diseased blood which remained well in the quarantine pasture were later placed in the Scribner exposure pen, where they again remained well.

In summarizing the experiments with the first drawing of serum from immune 1286, we find that 18 hogs were treated by the serum-simultaneous

1559	50	do	do	Sickened Aug. 9; died Aug. 22, 1906.				Do.
1560	40	do	do	Sickened Aug. 9; died Aug. 16, 1906.				Hemorrhages and ulcers.
1561	30	Pen check with hogs 1558, 1559, and 1560.		Sickened Aug. 18; died Sept. 3, 1906.				Do.
1712	50					Sept. 18, 1906	Sickened; died Oct. 1, 1906.	Hemorrhagic lesions.

[a] These animals were given double exposure to Scribner and Syphax strains of disease.

method, the dose of serum varying from 5 c. c. to 20 c. c., and that only one of these died from the vaccination, although all that received less than 15 c. c. of serum became sick. Of the 5 hogs which were injected with diseased blood alone, all died of hog cholera. Eight hogs were injected with serum alone, no ill effects whatever following the injection.

In regard to the exposure to hog cholera after vaccination, we find that all vaccinated hogs, whether treated with serum alone or with a combination of serum and disease-producing blood, were rendered completely immune from hog cholera for at least three weeks. It appears, however, from the death of hogs 1580 and 1581 that the serum of immune 1286 when given alone, even in doses of 20 c. c., does not afford protection to hogs weighing from 25 to 40 pounds for as long as two and one-half months.

In so far as the first drawing of serum from immune 1286 is concerned, we may conclude that (1) when given in sufficient dose it protects hogs completely from a fatal dose of disease-producing blood administered simultaneously with the serum; (2) that the hogs which survive vaccination by the serum-simultaneous method are rendered immune for a period of at least two and one-half months; (3) that hogs which show no visible reaction after this treatment are rendered quite as resistant as those which were made distinctly sick by the protective inoculation; (4) if a sufficient dose of serum is not given with the disease-producing blood the vitality of the vaccinated hog is apt to be impaired; (5) hogs vaccinated with serum alone are rendered immune for a period of three weeks, but this immunity does not last two and one-half months; (6) uninoculated hogs placed in pens with others vaccinated by the serum-simultaneous method did not contract hog cholera from them unless the vaccinated hogs themselves became distinctly sick.

SERUM FROM IMMUNE 1313 (QUICK METHOD).

EXPERIMENT III.—*Preliminary experiment with first drawing of serum.*

This experiment was carried out in the same manner as Experiment I, the doses of immune serum being 5 c. c., 10 c. c., and 15 c. c.; at the same time each hog was injected subcutaneously with 2 c. c. of disease-producing blood. Controls were injected at the same time with an equal amount of the same disease-producing blood alone. Of the 6 hogs treated with both serum and disease-producing blood, none showed any symptoms of sickness after vaccination, although both of the hogs which were injected with an equal amount of the same disease-producing blood alone became very sick and one of them died. The pen checks which were placed with each lot of vaccinated hogs did not contract disease from them, but the pen check with the controls 1751 and 1752 contracted disease from them and died.

Approximately three weeks after vaccination all of the treated hogs with their pen checks were placed in the quarantine pasture. (See Table 6.) The accidental outbreak of hog cholera in this pasture began about this time, so that these hogs may be considered as having been exposed to disease about the time that they were placed in the pasture. None of the vaccinated hogs became sick as a result of this exposure; 2 of the pen checks became sick and 1 died; the remaining check did not show symptoms of sickness. At a later date, in order to further test their immunity, the vaccinated hogs, with the check which did not become sick in the pasture, were placed in the Scribner exposure pen, but none of them became sick.

EXPERIMENT IV.—*Secondary experiment with first drawing of serum.*

The second experiment with this serum was carried out in the manner planned for secondary experiments except that the minimum dose of serum used was 10 c. c., even though 5 c. c. had given protection in the preliminary experiment. That this dose was not too great is shown by the sickness and death of one of the serum-simultaneous vaccinated hogs that received 10 c. c. of serum. As may be seen from Table 7, 6 hogs were injected with 10 c. c. of serum plus 2 c. c. of disease-producing blood, while 6 received 20 c. c. of serum with the disease-producing blood. Four hogs were injected with 10 c. c. of serum alone and a like number received 20 c. c. of serum alone. Two hogs were injected with disease-producing blood alone. In order to test the likelihood of hog cholera being conveyed through the agency of vaccinated hogs, 2 untreated healthy hogs were placed in each pen with the serum-simultaneous vaccinated hogs, and as a control 1 was placed in the pen with the 2 hogs that received disease-producing blood only.

Of the 6 hogs that received 10 c. c. of serum with disease-producing blood, 1 became sick and died, showing at autopsy the lesions of hog cholera. One of the hogs that was given 20 c. c. of serum with disease-producing blood died nearly seven weeks after vaccination, but the symptoms and lesions exhibited by this hog were such that a positive diagnosis of hog cholera could not be made. The other vaccinated hogs remained well, as did all of the checks in the pens with the vaccinated hogs. Both of the hogs that were given disease-producing blood alone died of hog cholera, and their check contracted the disease from them and died.

All of the surviving serum-simultaneous vaccinated hogs were exposed to infection at the same time, 4 being placed in the pasture

TABLE 6.—*Preliminary experiment with first drawing of serum from hog 1313 ("quick" immune—Scribner).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1733	40	5 c.c. serum and 2 c.c. disease-producing blood of hog 1664.	Sept. 26, 1906	Remained well	Oct. 15, 1906	Remained well	Dec. 22, 1906	Remained well	
1734	34	do	do	do	do	do	do	do	
1736	45	10 c.c. serum and 2 c.c. disease-producing blood of hog 1664.	do	do	do	do	do	do	
1737	40	do	do	do	do	do	do	do	
1739	50	15 c.c. serum and 2 c.c. disease-producing blood of hog 1664.	do	do	do	do	do	do	
1740	50	do	do	do	do	do	do	do	
1735	35	Pen check with hogs 1733 and 1734.		do	do	Died Nov. 7, 1906			Hemorrhagic lesions.
1738	40	Pen check with hogs 1736 and 1737.		do	do	Sickened, but recovered.		Not exposed	
1741	40	Pen check with hogs 1739 and 1740.		do	do	Remained well	Nov. 19, 1906	Remained well	
1751	40	2 c.c. disease-producing blood of hog 1664.	Sept. 26, 1906	Sickened Oct. 8; died Oct. 13, 1906.					Do.
1752	40	do	do	Sick Oct. 8 to Nov. 5, 1906; recovered.		Not exposed		Not exposed	
1753	35	Pen check with hogs 1751 and 1752.		Sickened Oct. 18; died Nov. 1, 1906.					Do.

TABLE 7.—*Secondary experiment with first drawing of serum from hog 1313 ("quick" immune—Scribner).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1777	45	10 c. c. serum and 2 c. c. disease-producing blood of hog 1711.	Oct. 10, 1906	Remained well			Oct. 25, 1906	Remained well	
1778	45	do	do	do			do	do	
1779	45	do	do	do			do	do	
1780	40	do	do	do	Oct. 25, 1906	Remained well, but unthrifty.	Dec. 22, 1906	Unthrifty; died Jan 15, 1907.	Ulcer in cecum.
1781	35	do	do	Sickened Oct. 20; died Nov. 19, 1906.					Hemorrhages and ulcers.
1782	40	do	do	Remained well	Oct. 25, 1906	Remained well	Dec. 22, 1906	Remained well	
1785	35	20 c. c. serum and 2 c. c. disease-producing blood of hog 1711.	do	do			Oct. 25, 1906	do	
1786	35	do	do	do	Oct. 25, 1906	Remained well	Dec. 22, 1906	do	
1787	40	do	do	do			Oct. 25, 1906	do	
1788	25	do	do	do	Oct. 25, 1906	Became unthrifty		Not exposed	
1789	45	do	do	do			Oct. 25, 1906	Remained well	
1790	45	do	do	Became unthrifty and died Nov. 27, 1906.					No marked lesions.
1793	60	10 c. c. serum alone	do	Remained well			Jan. 31, 1907	Died Feb. 21, 1907.	Hemorrhagic lesions.
1794	60	do	do	do			Oct. 29, 1906	Remained well	
1795	45	do	do	do			do	Sickened and died Nov. 17, 1906.	Do
1796	40	do	do	do			Jan. 31, 1907	Died Feb. 16, 1907.	No marked lesions.
1797	50	20 c. c. serum alone	do	do			Oct. 29, 1906	Remained well	
1798	65	do	do	do			Jan. 31, 1907	Died Feb. 19. 1907.	Hemorrhagic lesions.
1799	75	do	do	do			Oct. 29, 1906	Sickened and died Nov. 17, 1906.	Hemorrhages and ulcers.
1800	40	do	do	do			Jan. 31, 1907	Died Feb. 20, 1907.	Hemorrhagic lesions.
1783	35	Pen check with hogs 1777-1782.		do			do	Died Feb. 17, 1907.	Do.
1784	35	do		do			Oct. 25, 1906	Sickened and died Nov. 16, 1906.	Eaten by other hogs; no autopsy.
1791	25	Pen check with hogs 1785-1790.		do			do	Sickened and died Nov. 14, 1906.	Hemorrhagic lesions.
1792	25	do		do			Nov. 23, 1906	Became unthrifty; died Dec. 15, 1906.	No marked lesions.
1807	50	2 c. c. disease-producing blood of hog 1711.	Oct. 10, 1906	Sickened Oct. 15; died Oct. 28, 1906.					Hemorrhages and ulcers.
1808	35	do	do	Sickened Oct. 16; died					Hemorrhagic lesions

and 6 in the Scribner exposure pen fifteen days after vaccination. None of these hogs became distinctly sick, though hogs 1780 and 1788, which were exposed in the pasture, became unthrifty. Three of the hogs that survived the exposure in the pasture were placed in the Scribner exposure pen two months and twelve days after vaccination in order to further test their immunity. Of these 3 hogs 1, No. 1780, finally died more than three months after vaccination. The only lesion of hog cholera found at the autopsy of this hog was a single button ulcer in the cecum. In view of the lack of acute lesions and the unthriftiness which preceded the last exposure, it seems probable that this hog had contracted hog cholera before being placed in the Scribner exposure pen, and indeed the unthriftiness of this hog in the pasture may have been caused by a light attack of hog cholera following vaccination, the one ulcer found at autopsy being the only trace left of that attack.

Four of the hogs that were treated with serum alone were placed in the Scribner exposure pen nineteen days after vaccination, while the remaining 4 were first exposed three months and twenty-one days after vaccination. Of the first lot, 2 remained well, while 2 died of hog cholera; 2 checks exposed at the same time died of hog cholera. The amount of serum injected did not seem to affect the result of this exposure, as one of the survivors had received 10 c. c. and the other 20 c. c. of serum. Of the 4 that were first exposed three months and twenty-one days after injection of the serum, all died, and the pen check exposed at the same time also died of hog cholera.

Summary of experiments with serum from immune 1313.

In all, 18 hogs were treated by the serum-simultaneous method, the serum being used in doses of 5 c. c., 10 c. c., 15 c. c. and 20 c. c. Of these, 2 became sick and died, though it was impossible to make a positive diagnosis of hog cholera in the case of one of them. In the case of one other hog (1780) there is also some doubt whether death resulted from vaccination or from subsequent exposure to disease, but for convenience in summarizing, and because no symptoms of illness were observed after vaccination, the death of the hog is counted as due to exposure.

To determine the virulence of the disease-producing blood used in the serum-simultaneous vaccinations, 4 hogs were injected with disease-producing blood alone. All of these became sick and 3 died. Seven uninoculated hogs were placed in pens with the vaccinated hogs, and all remained well. Two similar unvaccinated hogs which were placed in pens with those injected with disease-producing blood alone died of hog cholera. None of the hogs injected with serum alone were made sick by the injection.

In testing the immunity of the treated hogs, 16 that were vaccinated by the serum-simultaneous method were exposed to hog cholera from fifteen to nineteen days after vaccination, and all remained well except 1780, which became unthrifty. Three of these hogs which had been exposed originally in the pasture were again exposed by being placed in the Scribner exposure pen seventy-three days after vaccination. One of these (1780) finally died as described above; the other 2 remained well.

Of 8 hogs that were treated with serum alone, none became sick from treatment, but 6 died when exposed to infection from nineteen days to three months and twenty-one days after vaccination. It is worthy of note that the 2 survivors were, with 2 others that succumbed, exposed only nineteen days after vaccination. Of 7 unvaccinated check hogs exposed along with the treated hogs, 6 became sick and 5 died.

The following conclusions may be drawn from the experiments with first drawing of serum from immune 1313:

(1) Serum from immune 1313 was sufficiently potent to protect the great majority of the injected hogs from a fatal dose of disease-producing blood adminsitered simultaneously with the serum.

(2) Hogs treated by the serum-simultaneous method, even though they became slightly sick, did not convey the disease to nonimmunes by association.

(3) Hogs vaccinated by a simultaneous injection of serum and disease-producing blood remained immune for at least fifteen days after vaccination.[a]

(4) Immunity subsequent to vaccination in hogs which received the maximum dose of serum with disease-producing blood was quite as firm as in those that received the minimum dose in the same manner.

(5) The immunity conferred by the serum of hog 1313 when administered alone in doses of 10 c. c. and 20 c. c. did not persist in full force for as long as nineteen days, and at the end of three months and twenty-one days it seemed to have completely disappeared.

SERUM FROM IMMUNE 1383 (SLOW METHOD).

EXPERIMENT V.—*Preliminary experiment with first drawing of serum.*

This first experiment with the first drawing of blood from immune 1383 was carried out in exactly the same manner as the preliminary experiments with the serum-simultaneous method, the serum being given in doses of 5 c. c., 10 c. c., and 15 c. c. Two hogs were injected with disease-producing blood alone, and 1 uninoculated hog was placed in each of the four pens used in this experiment. Table 8 shows that none of the vaccinated hogs became sick after treatment, nor did any of the check hogs in the same pens contract disease from

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[a] Other experiments have shown that immunity following serum-simultaneous injections lasts much longer than this.

TABLE 8.—*Preliminary experiment with first drawing of serum from hog 1383 ("slow" immune—Scribner).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1536	30	5 c. c. serum and 2 c. c. disease-producing blood of hog 1519.	July 30, 1906	Remained well	Oct. 25, 1906	Remained well	Nov. 16, 1906	Remained well	
1538	30	do	do	do	do	do	do	do	
1539	30	10 c. c. serum and 2 c. c. disease-producing blood of hog 1519.	do	do	do	do	do	do	
1540	35	do	do	do	do	do	do	do	
1542	40	15 c. c. serum and 2 c. c. disease-producing blood of hog 1519.	do	do	do	do			
1543	30	do	do	do	do	do	Nov. 19, 1906	Remained well	
1537	30	Pen check with hogs 1536 and 1538.		do	do	Sickened and died Oct. 25, 1906.			Hemorrhagic lesions.
1541	25	Pen check with hogs 1539 and 1540.		do	do	Sickened and died Oct. 27, 1906.			Do.
1544	25	Pen check with hogs 1542 and 1543.		do	do	Sickened and died Nov. 16, 1906.			Hemorrhages and ulcers.
1545	35	2 c. c. disease-producing blood of hog 1519.	July 30, 1906	Sickened Aug. 5; died Aug. 14, 1906.					Do.
1546	30	do	do	Sickened Aug. 7; died Aug. 21, 1906.					Hemorrhagic lesions.
1547[a]	25	Pen check with hogs 1545 and 1546.		Sick Aug. 15 to 25, 1906; recovered.			Aug. 25, 1906	Remained well	

[a] This hog received double exposure to Scribner and Syphax strains of disease.

them. Both of the hogs which were injected with the same dose of the same disease-producing blood as that used on the vaccinated hogs but without the serum, contracted hog cholera and died, and the pen check with these 2 hogs contracted hog cholera from them, but recovered.

The 6 vaccinated hogs with their 3 pen checks were placed in the quarantine pasture and were there accidentally exposed to disease about two and one-half months after vaccination; as a result of this exposure all 3 of the checks died of hog cholera, while the vaccinated hogs remained well.

Five of the vaccinated hogs had their immunity further tested by being placed in the Scribner exposure pen a little more than three and one-half months after vaccination. They again remained well, although the disease to which they were exposed was quite virulent.

The protection afforded against a fatal dose of disease-producing blood by even 5 c. c. of serum from immune 1383 was apparently complete. Instead of proceeding with a secondary experiment in the usual manner it was decided to determine the minimum amount of this serum required to protect against a fatal dose of diseased blood.

EXPERIMENT VI.—*Second experiment with first drawing of serum.*

No hogs were injected with serum alone in this experiment, all vaccinations being made by the serum-simultaneous method. The doses of serum used were reduced to 2½ c. c., 5 c. c., and 7½ c. c., and only 1 c. c. of disease-producing blood was used. This dose of blood was only half of that heretofore employed, but notwithstanding this it proved to be quite sufficient to infect unprotected hogs, for all of the hogs which received 1 c. c. of the disease-producing blood alone died of hog cholera, and the pen check exposed to them likewise contracted the disease and died.

Of the 6 vaccinated hogs, Nos. 1600 and 1601, which received only 2½ c. c. of serum with the disease-producing blood, became slightly sick after vaccination; the remaining vaccinated hogs which received larger doses of serum showed no symptoms of disease, and none of the pen checks exposed to the vaccinated hogs became sick. All of the vaccinated hogs with the pen checks were moved to the quarantine pasture and were there exposed to hog cholera approximately two months after vaccination. Two of the 3 pen checks died as a result of this exposure and at autopsy typical lesions of hog cholera were found. The third check evidently possessed a high degree of natural resistance to the disease, for it did not become distinctly sick in the pasture nor in the exposure pen, where it was placed later.

TABLE 9.—*Second preliminary experiment with first drawing of serum from hog 1383 ("slow" immune—Scribner).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1600	35	2½ c. c. serum and 1 c. c. disease-producing blood of hog 1559.	Aug. 18, 1906	Sick Aug. 25 to 27, 1906, but apparently recovered.	Oct. 15, 1906	Sickened latter part of November and died Dec. 8, 1906.[a]			Intestinal ulcers.
1601	30	do	do	Slightly sick, but recovered.	do	Remained well	Dec. 22, 1906	Remained well	
1603	50	5 c. c. serum and 1 c. c. disease-producing blood of hog 1559.	do	Remained well	do	do	Nov. 19, 1906	do	
1604	35	do	do	do	do	Sickened and died Oct. 29, 1906.			No typical lesions.
1606	40	7½ c. c. serum and 1 c. c. disease-producing blood of hog 1559.	do	do	do	Remained well	Nov. 19, 1906	Remained well	
1607	40	do	do	do	do	do	Nov. 22, 1906	do	
1602	35	Pen check with hogs 1600 and 1601.		do	do	Sickened and died Oct. 27, 1906.			Hemorrhages and ulcers.
1605	35	Pen check with hogs 1603 and 1604.		do	do	Remained well	Nov. 16, 1906	Became unthrifty.	
1608	40	Pen check with hogs 1606 and 1607.		do	do	Sickened and died			Do.
1609	35	1 c. c. disease-producing blood of hog 1559.	Aug. 18, 1906	Sickened Aug. 24; died Aug. 27, 1906.					Lesions indicating infection with gas bacillus.
1610	35	do	do	Sickened Aug. 24; died Sept. 1, 1906.					Hemorrhages and ulcers.
1611	35	do	do	Sickened Aug. 24; died Sept. 4, 1906.					Do.
1612	35	do	do	do					Do.
1613	30	Pen check with hogs 1609, 1610, 1611, and 1612.		Sickened Aug. 30; died Sept. 5, 1906.					Do.

[a] Probably died from vaccination.

Two of the 6 vaccinated hogs died while in the quarantine pasture; the remaining 4 did not become sick. From the autopsy findings there seems to be little room for doubt that the death of hog 1600, 1 of the 2 that died in the quarantine pasture, was due to hog cholera. It has been stated that this hog showed symptoms of illness shortly after vaccination. If this was due to a mild attack of hog cholera, as was probably the case, then it is hardly conceivable that the hog could have contracted hog cholera in the pasture, unless indeed this be a rare instance of failure to acquire immunity through an attack of the disease. It seems to us more likely that hog 1600 never completely recovered from the mild attack of hog cholera which followed vaccination, and that when placed in the rather crowded quarantine pasture it succumbed. The autopsy showed only the lesions which are found in the chronic type of hog cholera. The death of hog 1604, the other vaccinated animal which died in the pasture, can not be explained in the same way, for this hog did not show symptoms of illness following vaccination, and its death, if caused by hog cholera, was no doubt due to a failure of the vaccine to afford protection for two months, the time which intervened between vaccination and exposure. The fact, however, that hog 1603 (treated in the same manner as hog 1604), hog 1601, which received half as much serum, and hogs 1606 and 1607, which received more serum, all remained well, though subjected to the same exposure as hog 1604, points strongly to the likelihood that the death of hog 1604 was due to unusual susceptibility, or else to some cause other than hog cholera. This latter possibility must not be overlooked, as the lesions found at autopsy were not typical of that disease and as the conditions in the pasture were not conducive to thriftiness. Three of the surviving vaccinated hogs—1601, 1603, and 1606—were later placed in the Scribner exposure pen, where they again remained well.

Experiments V and VI show that the minimum amount of serum from hog 1383 required to protect with certainty from a simultaneous injection of a lethal dose of disease-producing blood probably lies in the neighborhood of 5 c. c. for hogs weighing from 30 to 35 pounds.

EXPERIMENT VII.—*Second drawing of serum from immune 1383.*

It will be remembered that blood was drawn from each of the immunes at different times after hyperimmunization, but in the experiments heretofore described only serum from the first drawings of blood was used. In Experiments VII and VIII serum from the second and third drawings of blood from hog 1383 were tested, and although no attempt was made to determine accurately the potency of this serum, doses of 10 c. c. were found to give full protection from a lethal dose of disease-producing blood.

TABLE 10.—*Preliminary experiment with second drawing of serum from hog 1383 ("slow" immune—Scribner).*

No. of hog.	Weight.	Materialinjected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1647	75	10 c. c. serum + 2 c. c. disease-producing blood from hogs 1568 and 1614.	Sept. 3, 1906	Remained well	Oct. 15, 1906	Remained well	Dec. 22, 1906	Remained well	
1648	50	do	do	do	do	do	do	do	
1649	75	20 c. c. serum + 2 c. c. disease-producing blood from hogs 1568 and 1614.	do	do	do	do	do	do	
1650	55	do	do	do	do	do	Nov. 19, 1906	do	
1651 [a]	90	20 c. c. serum alone	do	do			Sept. 20, 1906	do	
1652 [a]	55	10 c. c. serum alone	do	do			do	do	
1661	55	2 c.c. disease-producing blood from hogs 1568 and 1614.	do	Sickened Sept. 9; died Sept. 14, 1906.					Hemorrhages and ulcers.
1662	45	do	do	Sickened Sept. 9; died Sept. 17, 1906.					Hemorrhagic lesions.
1663	45	do	do	Sickened Sept. 9; died Oct. 6, 1906.					Hemorrhages and ulcers.
1664	40	Pen check with hogs 1661, 1662, and 1663.		Sickened Sept. 19; killed Sept. 26, 1906.					Do.

[a] These hogs were given double exposure to Scribner and Syphax strains of disease.

Table 10 shows that 4 hogs vaccinated by a simultaneous injection of disease-producing blood and the second drawing of serum remained well, although 3 checks which received the disease-producing blood alone all died of hog cholera. In this experiment 2 hogs were also injected with serum alone. These 2 were placed in the Scribner exposure pen seventeen days after receiving the serum injection. They remained well there and were removed to the Syphax exposure pen four weeks later, and here they again remained well. The virulence of the disease to which they were exposed in the Syphax pen is shown by the death of unprotected checks exposed to the same infection. (See Experiment XVI.)

The 4 hogs vaccinated by the serum-simultaneous method were placed in the quarantine pasture, and were there, with a number of others, accidentally exposed to infection approximately six weeks after vaccination. They all remained well and were transferred to the Scribner exposure pen three and one-half months after vaccination. No symptoms of disease followed this second exposure.

TABLE 11.—*Preliminary experiment with third drawing of serum from hog 1383 ("slow" immune—Scribner).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1653	50	10 c. c. serum and 2 c. c. disease-producing blood of hogs 1568 and 1614.	Sept. 3, 1906	Remained well	Oct. 15, 1906	Remained well	Dec. 22, 1906	Remained well	
1654	50	do	do	do	do	do	Nov. 16, 1906	do	
1655	90	20 c. c. serum and 2 c. c. disease-producing blood of hogs 1568 and 1614.	do	do	do	do	Dec. 22, 1906	do	
1656	40	do	do	do	do	do	do	do	
1661	55	2 c. c. disease-producing blood of hogs 1568 and 1614.	do do	Sickened Sept. 9; died Sept. 14, 1906.					Hemorrhages and ulcers.
1662	45	do	do	Sickened Sept. 9; died Sept. 17, 1906.					Hemorrhagic lesions.
1663	45	do	do	Sickened Sept. 9; died Oct. 6, 1906.					Hemorrhages and ulcers.
1664	40	Pen check with hogs, 1661, 1662, and 1663.		Sickened Sept. 19; killed Sept. 26, 1906.					Do.

EXPERIMENT VIII.—*Third drawing of serum from immune 1383.*

This experiment with the third drawing of serum was conducted in the same manner as the experiment with the second drawing, except that no hogs were vaccinated with serum alone. The results were in entire accord with those of Experiment VII. The 4 hogs vaccinated by the serum-simultaneous method, the serum being given in doses of 10 c. c. and 20 c. c. remained perfectly well. The death of the 3 control hogs, 1661, 1662, and 1663, shows the virulence of the diseased blood used in the experiment. The vaccinated hogs were exposed to hog cholera in the quarantine pasture six weeks after vaccination, and were given a later exposure in the Scribner exposure pen; none of them showed any symptoms of illness following either exposure.

Summary of experiments with serum from immune 1383.

In summarizing the results obtained with the serum from immune 1383, it should be noted first of all that in so far as our results indicate there is no difference in the protective power of the first, second, and third drawings, although it is true that no attempt was made to determine the minimum dose of serum of the second and third drawings required to protect from a fatal dose of diseased blood.

In all, 20 hogs were treated by the serum-simultaneous method, the doses of serum used varying from 2½ c. c. to 20 c. c., and the dose of disease-producing blood being from 1 c. c. to 2 c. c. to each hog. At the same time 12 hogs were injected with equivalent doses of the same disease-producing blood alone. Of the 20 vaccinated hogs only 1 (1600) died from the treatment, and this hog received but 2½ c. c. of serum. Of the 12 hogs which received the same disease-producing blood without any serum all died.

In the pens with the hogs vaccinated by the serum-simultaneous method, 6 checks were used to determine the likelihood of the disease being transmitted by vaccinated hogs. None of these checks became sick, but of 4 checks placed in the pens with hogs injected with disease-producing blood only, all contracted disease.

Of the 19 hogs which survived vaccination by the serum-simultaneous method, all were exposed to hog cholera in the quarantine pasture from six weeks to two and one-half months after vaccination. Only 1 died from this exposure (1604), and, as previously explained, we can not be quite certain that this death was really due to hog cholera. Six pen checks, which had remained well during exposure to the vaccinated hogs, were exposed in the pasture with the vaccinated animals, and as a result 5 died of hog cholera.

Only 2 hogs were vaccinated with serum alone. These were first exposed to disease seventeen days after vaccination and remained well. Later exposure to disease in the Scribner and Syphax exposure pens did not produce sickness in these hogs.

From the results of the experiments with serum from hog 1383 we may draw the following conclusions:

1. Serum from hog 1383, when given in sufficient dose, protects nonimmunes from an otherwise fatal dose of disease-producing blood administered simultaneously with the serum.

2. The serum alone in doses of 10 c. c. protects from infection occurring within 17 days after the administration of the serum.

3. Immunity conferred by the serum-simultaneous method lasts for two and one-half months at least.

4. Hogs treated by the serum-simultaneous method, and which are not made ill by vaccination, do not communicate hog cholera to nonimmunes by association.

5. The duration of immunity produced by the serum-simultaneous method of vaccination does not seem to be shortened by increasing the dose of the serum considerably above the amount necessary to prevent the occurrence of a distinct reaction.

SERUM FROM IMMUNE 1403 (SLOW METHOD).

Although two separate experiments were carried out with serum from immune 1403, very small doses of serum were not used, the experiments previously noted having shown that except in the case of unusually potent serum, such as that from immune 1383, 10 c. c. was as small a dose as could be relied upon.

EXPERIMENT IX.—*Preliminary experiment with first drawing of serum from immune 1403.*

In this experiment only the serum-simultaneous method of vaccination was used. Six hogs were vaccinated, the dose of serum being 10 c. c., 15 c. c., and 20 c. c. The same amount of disease-producing blood, 2 c. c., was used in all cases, and controls were inoculated with 2 c. c. of the same disease-producing blood alone. Only 1 (1553) of the 6 treated hogs showed signs of sickness after vaccination, while all of the hogs that were injected with the disease-producing blood alone died of hog cholera. The pen checks exposed to the vaccinated hogs did not become sick, although the check exposed to the hogs which received disease-producing blood alone contracted hog cholera and died.

Several weeks after vaccination 5 of the treated hogs with their 3 pen checks were placed in the quarantine pasture, and 4 of them were there exposed to hog cholera approximately two and one-half months after vaccination. It will be remembered that this outbreak of disease in the quarantine pasture occurred about October 15, 1906, so that hog 1549, which died September 16 (see Table 12), was not exposed to hog cholera after vaccination. Of the 4 vaccinated hogs which were exposed in the pasture, none showed symptoms of hog cholera, though 1 became unthrifty. All 3 of the pen checks died in the pasture and at autopsy showed distinct lesions of hog cholera.

The 4 vaccinated hogs which survived this exposure were placed in the Scribner exposure pen three and one-half months after vaccination. One of these 4 hogs (1556) was unthrifty when placed in the exposure pen and died about two weeks after exposure. The autopsy did not disclose lesions of hog cholera and the death was probably due to other causes. Hog 1552, another one of those placed in the Scribner exposure pen, also died a short while after exposure, but did not show positive lesions of hog cholera at autopsy. This hog when exposed was small and unthrifty, and while we can not state the cause of death with certainty, there is a strong probability that, as in the case of hog 1556, the death was not due to hog cholera. The other 2 vaccinated hogs remained well in the exposure pen.

TABLE 12.—*Preliminary experiment with first drawing of serum from hog 1403 ("slow" immune—Scribner).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1549	30	10c.c. serum and 2c.c. disease - producing blood of hog 1531.	Aug. 4,1906	Remained well		Sickened and died Sept. 16, 1906.[a]			Death due to intestinal perforation caused by worms. No lesions of cholera. Bile duct occluded by intestinal worms.
1550	40	do	do	do	Oct. 15,1906	Remained well	Nov. 19,1906	Remained well	
1552	25	15c.c. serum and 2c.c. disease - producing blood of hog 1531.	do	do	do	do	Nov. 16,1906	Became unthrifty; died Nov. 27, 1906.[b]	No marked lesions.
1553	25	do	do	Slightly sick Aug. 14 to 18, 1906; recovered.					
1555	40	20c.c. serum and 2c.c. disease - producing blood of hog 1531.	do	Remained well	Oct. 15,1906	Remained well	Nov. 19,1906	Remained well	
1556	45	do	do	do	do	Became unthrifty	Nov. 17,1906	Sickened and died Nov. 30, 1906.[b]	Do.
1551	25	Pen check with hogs 1549 and 1550.		do	do	Sickened and died Oct. 31, 1906.			Hemorrhages and ulcers.
1554	20	Pen check with hogs 1552 and 1553.		do	do	do			Do.
1557	20	Pen check with hogs 1555 and 1556.		do	do	Sickened and died Nov. 3, 1906.			Do.
1558	20	2 c. c. disease-producing blood of hog 1531.	Aug. 8,1906	Sickened Aug. 9; died Aug. 16, 1906.					Hemorrhagic lesions.
1559	50	do	do	Sickened Aug. 9; died Aug. 22, 1906.					Do.
1560	40	do	do	Sickened Aug. 9; died Aug. 16, 1906.					Hemorrhages and ulcers.
1561	30	Pen check with hogs 1558, 1559, and 1560.		Sickened Aug. 18; died Sept. 3, 1906.					Do.

[a] Died before being exposed to hog cholera.

[b] Probably did not die of hog cholera.

EXPERIMENT X.—*Second experiment with first drawing of serum from immune 1403.*

In Experiment X 12 hogs were treated by the serum-simultaneous method, half of these being given 10 c. c. and the other half 20 c. c. of serum. Eight hogs were given serum alone in doses of 10 c. c. and 20 c. c., and 4 hogs were given disease-producing blood alone in the same dose as was used for the serum-simultaneous vaccinations. Checks were placed in the pens with both of the serum-simultaneous lots of hogs and also with those injected with disease-producing blood alone. Table 13 shows that none of the vaccinated hogs became sick, nor did they communicate disease to the exposed pen checks. All of the hogs which received disease-producing blood alone died, and they communicated hog cholera to the check which was placed in the pen with them.

For the purpose of testing the subsequent immunity of the vaccinated hogs, these were divided into two lots. One lot was to be exposed to hog cholera within a few weeks after vaccination, while the other was not to be exposed for several months. The first lot was exposed in the Scribner exposure pen, 4 of the hogs treated by serum alone being placed there thirteen days after vaccination. These were followed eleven days later by 6 of those treated by the serum-simultaneous method (see Table 13) and 1 of the pen checks. This pen check died of hog cholera; 1 of the hogs vaccinated with serum alone became very slightly sick, but recovered. The other vaccinated hogs remained well, but in order to secure further data concerning the behavior of hogs immune from one strain of disease when exposed to another all of these vaccinated hogs were later placed in the Syphax exposure pen, where they all remained well.

The other lot of vaccinated hogs in this experiment, with 2 checks, was placed in the quarantine pasture and there exposed to hog cholera seven weeks after vaccination. Both checks contracted hog cholera; one died, and the other was killed when in a moribund contion, and at autopsy showed typical lesions of that disease. One of the hogs (1638) treated with serum alone also became sick following this exposure and died of hog cholera, as did hog 1628, which was treated with 20 c. c. of serum plus 2 c. c. of disease-producing blood. None of the other vaccinated hogs became sick, and all of them, except hog 1620, which was unthrifty, were placed in the Scribner exposure pen about four months after vaccination. None of them contracted hog cholera from this exposure.

Summary of experiments with serum from immune 1403.

Only the first drawing of serum was used. In all 18 hogs were treated by the serum-simultaneous method, the doses of serum given in conjunction with 2 c. c. of disease-producing blood being 10 c. c.,

TABLE 13.—*Secondary experiment with first drawing of serum from hog 1403 ("slow" immune—Scribner).*

No. of hog.	Weight (pounds.)	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
1616 [a]	40	10 c. c. serum and 2 c. c. disease-producing blood of hog 1598.	Aug. 25, 1906	Remained well			Sept. 18, 1906	Remained well	
1617 [a]	35	do	do	do			do	do	
1618 [a]	35	do	do	do			do	do	
1619	40	do	do	do	Oct. 15, 1906	Remained well	Dec. 22, 1906	Became unthrifty.	
1620	35	do	do	do	do	Became unthrifty			
1621	35	do	do	do	do	Remained well	Dec. 22, 1906	Remained well	
1624 [a]	40	20 c. c. serum and 2 c. c. disease-producing blood of hog 1598.	do	do			Sept. 18, 1906	do	
1625 [a]	40	do	do	do			do	do	
1626 [a]	40	do	do	do			do	do	
1627	45	do	do	do	Oct. 15, 1906	Remained well	Dec. 22, 1906	do	
1628	40	do	do	do	do	Sickened and died Nov. 6, 1906.			Hemorrhages and ulcers.
1629	40	do	do	do	do	Remained well	Dec. 22, 1906	Remained well	
1632 [a]	50	10 c. c. serum alone	do	do			Sept. 7, 1906	Slightly sick, but recovered.	
1633 [a]	45	do	do	do			do	Remained well	
1634	45	do	do	do	Oct. 15, 1906	Remained well	Dec. 22, 1906	do	
1635	45	do	do	do	do	do	do	do	
1636 [a]	60	20 c. c. serum alone	do	do			Sept. 7, 1906	do	
1637	40	do	do	do	Oct. 15, 1906	Remained well	Nov. 19, 1906	do	
1638	50	do	do	do	do	Sickened and died Nov. 11, 1906.			Hemorrhagic lesions.
1639 [a]	45	do	do	do			Sept. 7, 1906	Remained well	
1622	35	Pen check with hogs 1616 to 1621.		do	Oct. 15, 1906	Sickened and died Nov. 11, 1906.			Do.
1623	25	do		Killed by other hogs.					No pathological lesions.
1630	35	Pen check with hogs 1624 to 1629.		Remained well			Sept. 18, 1906	Sickened and died Oct. 10, 1906.	Hemorrhages and ulcers.
1631	40	do		do	Oct. 15, 1906	Sickened and was killed Nov. 1, 1906.			Do.
1640	40	2 c. c. disease-producing blood of hog 1598.	Aug. 25, 1906	Sickened Sept. 1; died Sept. 9, 1906.					Hemorrhagic lesions.
1641	40	do	do	Sickened Sept. 1; died Sept. 8, 1906.					Do.
1642	40	do	do	Sickened Sept. 1; died Sept. 10, 1906.					Hemorrhages and ulcers.
1643	35	do	do	do					Hemorrhagic lesions.
1644	25	Pen check with hogs 1640 to 1643.		Sickened Sept. 5; died Sept. 13, 1906.					Hemorrhages and ulcers.

[a] These hogs were given double exposure to Scribner and Syphax strains of disease.

15 c. c., and 20 c. c. Of these 18 hogs 1 became slightly sick as a result of vaccination but soon recovered, while the others remained well. As controls on the virulence of the disease-producing blood, as well as on the protective power of the serum, 7 hogs were injected with disease-producing blood alone in the same dose as that given the vaccinated hogs. All of these controls died of hog cholera. To test the danger of vaccinated hogs conveying the disease to nonimmunes, 6 checks were exposed in the pens with those treated by the serum-simultaneous method. None of these checks became sick, although the 2 checks exposed to hogs injected with disease-producing blood alone contracted hog cholera, as was to be expected.

Of the 18 hogs treated by the serum-simultaneous method which were exposed to infection at various times after vaccination, 1 contracted hog cholera and died; none of the others became sick.

Of 8 hogs treated with the serum alone, 1 contracted hog cholera when exposed seven weeks after vaccination; the others remained well.

Of 6 unvaccinated hogs exposed along with the treated animals, all died of hog cholera.

These experiments warrant the following conclusions:

(1) Serum from immune 1403 when given in sufficient doses affords perfect protection from an otherwise fatal dose of disease-producing blood administered simultaneously.

(2) Hogs vaccinated by the serum-simultaneous method, with rare exceptions, remain immune for at least seven weeks after vaccination.

(3) Hogs treated by the serum-simultaneous method, if not made ill by the treatment, do not convey hog cholera to others by association.

(4) For seven weeks after vaccination immunity in hogs treated with serum alone is as firm as in those treated by the serum-simultaneous method.

(5) Hogs immunized from one strain of hog cholera are also immune from other strains of the same disease.

TESTS OF SERUM FROM HOGS HYPERIMMUNIZED WITH BLOOD FROM THE SYPHAX OUTBREAK.

SERUM FROM IMMUNE 1392 (QUICK METHOD).

EXPERIMENT XI.—*First drawing of serum.*

The results obtained in Experiment XI did not differ materially from those of similar experiments carried out with serum from immunes treated with the Scribner disease-producing blood. The smallest dose of serum used was 10 c. c., and although the 2 hogs given this dose did not become visibly sick from the serum-simultaneous vaccination, the fact that 1 of those given 15 c. c. as well as 1

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1588	40	10 c. c. serum and 2 c. c. disease-producing blood of hog 1560.	Aug. 14, 1906	Remained well	Oct. 15, 1906	Remained well	Dec. 16, 1906	Remained well	
1589	35	do	do	do	do	do	Nov. 19, 1906	do	
1591	35	15 c. c. serum and 2 c. c. disease-producing blood of hog 1560.	do	Sick Aug. 19 to 23, 1906; recovered.	do	do	do	do	
1592	30	do	do	Remained well	do	do	do	do	
1594	40	20 c. c. serum and 2 c. c. disease-producing blood of hog 1560.	do	Sick Aug. 23 to Sept. 6, 1906; recovered.	do	do			
1595	40	do	do	Remained well	do	do			
1590	40	Pen check with hogs 1588 and 1589.		do	do	Sickened and died			Hemorrhages and ulcers.
1593	35	Pen check with hogs 1591 and 1592.		do	do	do			Do.
1596	40	Pen check with hogs 1594 and 1595.		do	do	Became unthrifty and died Dec. 28, 1906.			Lung lesions indicating pneumonia.
1597	35	2 c. c. disease-producing blood of hog 1560.	Aug. 14, 1906	Sickened Aug. 21; died Aug. 31, 1906.					Hemorrhages and ulcers.
1598	40	do	do	Sickened Aug. 21; died Aug. 29, 1906.					Hemorrhagic lesions.
1599	40	Pen check with hogs 1597 and 1598.		Sickened Aug. 27; died Sept. 19, 1906.					Do.

TABLE 15.—*Secondary experiment with first drawing of serum from hog 1392 ("quick" immune—Syphax).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1685	45	10 c. c. serum and 2 c. c. disease-producing blood of hog 1662.	Sept. 15, 1906	Remained well			Oct. 2, 1906	Remained well	
1686	30	do	do	do			do	do	
1687	45	do	do	do	Oct. 15, 1906	Remained well	Dec. 22, 1906	Killed by hogs	Badly mutilated; no autopsy.

1688	35	do	do	do	do	do		
1689	55	do	do	do	do	do	Dec. 22, 1906	Remained well
1690	55	do	do	do			Oct. 2, 1906	do
1693	45	20 c. c. serum and 2 c. c. disease-producing blood of hog 1662.	do	do			do	do
1694	50	do	do	do			do	do
1695	40	do	do	do			do	do
1696	45	do	do	Sick (?)	Oct. 15, 1906	Sickened; died Nov. 7, 1906.[a]			Ulceration of cecum.
1697	45	do	do	Remained well	do	Remained well	Dec. 22, 1906	Remained well
1698	35	do	do	do	do	do	do	do
1701	35	10 c. c. serum alone	do	do	do	do	do	do
1702	40	do	do	do	do	do	do	Unthrifty; killed by hogs.	No pathological lesions.
1703[b]	45	do	do	do			Sept. 26, 1906	Remained well
1704	40	do	do	do			do	Sickened; died Nov. 18, 1906.	No marked lesions.
1705	55	20 c. c. serum alone	do	do	Oct. 15, 1906	Became unthrifty; killed Jan. 2, 1907.			No pathological lesions.
1706[b]	30	do	do	do			Sept. 26, 1906	Remained well
1707	50	do	do	do	Oct. 15, 1906	Sickened; died Nov. 14, 1906.			Hemorrhages and ulcers.
1708[b]	50	do	do	do			Sept. 26, 1906	Remained well
1691	35	Pen check with hogs 1685 to 1690.		do			Oct. 2, 1906	Sickened; died Oct. 17, 1906.	Do.
1692	35	do		do	Oct. 15, 1906	Sickened; died Oct. 30, 1906.			Hemorrhagic lesions.
1699	35	Pen check with hogs 1693 to 1698.		do			Oct. 2, 1906	Sickened; died Oct. 23, 1906.	Do.
1700	30	do		do	Oct. 15, 1906	Sickened; died Nov. 3, 1906.			Do.
1709	40	2 c. c. disease-producing blood.	Sept. 15, 1906	Sickened Sept. 25; died Sept. 28, 1906.					Hemorrhages and ulcers.
1710	40	do	do	Sick Sept. 24 to Oct. 15, 1906; recovered.			Oct. 25, 1906	Remained well
1711	35	Pen check with hogs 1709 and 1710.		Sickened Oct. 8; died Oct. 14, 1906.					Do.

[a] This hog probably died from vaccination.

[b] These hogs were given double exposure to Scribner and Syphax strains of disease.

given 20 c. c. of serum did become sick makes it quite probable that less than 10 c. c. of this serum could not be used with 2 c. c. of virulent blood with safety. (See Table 14.)

None of the hogs treated by the serum-simultaneous method died, although 2 became sick, as already stated; notwithstanding the sickness of the 2 vaccinated hogs, the untreated pen checks exposed to them did not become sick. Both of the hogs injected with disease-producing blood alone became sick and died of hog cholera, and they also communicated disease to their pen check.

Following out the usual plan, the surviving hogs from this experiment were placed in the quarantine pasture. These hogs had been vaccinated two months when the accidental outbreak of disease occurred in the pasture, but none of them became sick from the exposure. Two of the 3 checks which were placed in the pasture with the treated animals died of hog cholera; the third check became unthrifty and died, but apparently did not suffer from hog cholera. Four of the vaccinated hogs were later transferred to the Scribner exposure pen and again remained well.

EXPERIMENT XII.—*Second experiment with first drawing of serum from immune 1892.*

In Experiment XII 12 hogs were treated by the serum-simultaneous method, 8 were treated with serum alone, and 2 were injected with disease-producing blood alone. Four uninoculated hogs were placed in the pens with the serum-simultaneous hogs, and 1 with the 2 that received disease-producing blood only. As a result of the treatment, as far as could be observed none of the vaccinated hogs showed symptoms of illness, and the checks in the pens with them also remained well. With the hogs that received disease-producing blood alone the result was quite different, for both contracted hog cholera and one died; the pen check that was exposed to these hogs also became sick and died of hog cholera. (See Table 15.)

For the purpose of testing the immunity possessed by the vaccinated hogs at different lengths of time after vaccination, these hogs were divided into two lots, 6 of the serum-simultaneous vaccinated hogs being placed in the Syphax exposure pen seventeen days after vaccination and 4 of the hogs treated with serum alone in the same pen eleven days after vaccination. Table 15 shows the results of these exposures. Of the 6 hogs treated by the serum-simultaneous method and exposed seventeen days after vaccination, all remained well; of the 4 hogs vaccinated with serum alone and exposed in the Syphax exposure pen eleven days after vaccination, 1 (1704), after being sick a long time, died about two months later, probably of hog cholera, although the lesions found at autopsy were slight and not such as would be expected from a chronic case of hog cholera. The other 3 hogs (1703, 1706, and 1708), vaccinated with serum alone, remained well and were later exposed to the Scribner disease without being made sick. Two of the uninoculated check hogs were placed in the exposure pen with the serum-simultaneous hogs, and both died of hog cholera.

The exposure of the second lot of hogs in this experiment took place in the quarantine pasture thirty days after vaccination. Of the 6 serum-simultaneous hogs that were exposed there, 1 (1696) did not thrive, and finally died of hog cholera seven weeks after vaccination, while the others remained well. The death of hog 1696 was probably due to a mild form of disease caused by the original serum-simultaneous vaccination, as the hog at autopsy showed the lesions of the chronic type of hog cholera, though it had been exposed to disease in the pasture only three weeks at the time of its death. Of the 4 hogs treated with serum alone, which were accidentally exposed in the quarantine pasture thirty days after vaccination, 1 (1707) died of hog cholera. The others did not contract the disease. Both of the pen checks that were placed in the pasture with the vaccinated hogs died of hog cholera.

Summary of experiments with serum from immune 1392.

A summary of the results obtained through the use of the first drawing of serum from immune 1392 shows that of 18 hogs treated by the serum-simultaneous method, the serum being used in doses of 10 c. c., 15 c. c., and 20 c. c., 1 became sick and 1 (1696; see above) died from the treatment. Of 4 hogs injected with the same amount of the same disease-producing blood as that used for the serum-simultaneous treatment, all became sick and 3 died.

All of the surviving treated hogs with the surviving checks were exposed to infection after vaccination. All 17 of the serum-simultaneous hogs, exposed seventeen to thirty days after vaccination, remained well; 2 of the 8 hogs treated with serum alone died of hog cholera when exposed eleven to thirty days after treatment, while of 4 checks exposed in the same manner as the treated hogs, all died of hog cholera.

As a result of these experiments it will be seen that—

(1) The serum of hog 1392, in doses of 10 c. c. or more, was sufficient to protect hogs from a fatal dose of disease-producing blood administered simultaneously with the serum.

(2) Hogs treated by simultaneous injections of serum from hog 1392, together with disease-producing blood, remained immune for at least thirty days after vaccination.

(3) Hogs treated by the serum-simultaneous method, even when they became distinctly sick, did not convey disease to unprotected animals which associated with them.

TABLE 16.—*Preliminary experiment with first drawing of serum from hog 1274 ("quick" immune—Syphax).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1715	50	5 c. c. serum and 2 c. c. disease - producing blood of hog 1680.	Sept. 21, 1906	Remained well	Oct. 15, 1906	Died Nov. 18, 1906			Doubtful lesions of hog cholera.
1716	40	do	do	do	do	Remained well	Dec. 12, 1906	Remained well	
1718	40	10 c. c. serum and 2 c. c. disease - producing blood of hog 1680.	do	Sick Sept. 30 to Oct. 8, 1906; recovered.	do	Became unthrifty and killed by hogs.			No autopsy.
1719	50	do	do	do		Became unthrifty and was not exposed.			
1721	45	15 c. c. serum and 2 c. c. disease - producing blood of hog 1680.	do	Remained well	Oct. 15, 1906	Remained well	Dec. 22, 1906	Remained well	
1722	40	do	do	do	do	do	do	do	
1717	40	Pen check with hogs 1715 and 1716.		do	do	Sickened but recovered.	Dec. 12, 1906	Died Jan. 17, 1907.	Congestion of lungs and pleuræ.
1720	40	Pen check with hogs 1718 and 1719.		do	do	Became unthrifty and killed by hogs.			No autopsy.
1723	35	Pen check with hogs 1721 and 1722.		do	do	Died Nov. 11, 1906			Hemorrhages and ulcers.
1730	40	2 c. c. of disease-producing blood of hog 1680.	Sept. 21, 1906	Sickened Sept. 27; died Oct. 1, 1906.					Hemorrhagic lesions.
1731	50	do	do	Sickened Sept. 27, 1906; killed when moribund.					Do.
1732	40	Pen check with hogs 1730 and 1731.		Sickened Oct. 4; died Oct. 13, 1906.					Hemorrhages and ulcers.

(4) The immunity produced by injections of serum alone from hog 1392 did not seem to be as complete as that produced by a simultaneous injection of serum and disease-producing blood.

(5) Hogs immunized with serum prepared through the use of one strain of disease were immune when exposed to another strain of disease.

SERUM FROM IMMUNE 1274 (QUICK METHOD).

EXPERIMENT XIII.—*Preliminary experiment with first drawing of serum.*

The preliminary experiment with the first drawing of serum from immune 1274 consisted of serum-simultaneous vaccinations only, a certain number of controls being, of course, used. The results of this experiment were not entirely successful, as may be seen from Table 16.

First of all, we find that serum from hog 1274 probably has distinct protective power when injected simultaneously with a fatal dose of disease-producing blood. This is indicated by the death of the 2 hogs that received disease-producing blood alone, and the survival of all those treated with serum. At the same time it is surprising that the 2 hogs that received 10 c. c. of serum with the disease-producing blood should have become distinctly sick, whereas the 2 that received only 5 c. c. of serum remained well. This result could only be explained on the ground of unusual susceptibility on the part of hogs 1718 and 1719, or because hogs 1715 and 1716, which received only 5 c. c. of serum, were exceptionally resistant to the disease. In the light of this experiment only, the latter supposition seems to be the most reasonable explanation of the conflicting results, for when the vaccinated hogs with their pen checks were exposed to hog cholera in the quarantine pasture three weeks after vaccination only one of the three pen checks (1723) died of hog cholera. It is true that one other sickened, but it recovered, and the third check never became distinctly sick in the quarantine pasture. The subsequent death of this check (1717) in the exposure pen can not be attributed to hog cholera. It appears, therefore, that the lot of hogs used in this experiment taken as a whole were probably more than normally resistant to hog cholera, and for this reason too great stress should not be laid upon the results. At the same time the serum must have given the vaccinated hogs a certain degree of protection, for both of the controls injected with disease-producing blood alone became very sick, one of them died, and the other was killed to secure blood for other experiments, and at autopsy both showed characteristic lesions of hog cholera. In contrast to this is the behavior of the hogs which received the same disease-producing blood in combination with the serum, not one of these having died from vaccination. When this lot of hogs was exposed to disease in the quarantine pasture one of the pen checks died of hog cholera, one became sick but recovered, while the other never showed marked symptoms of illness. With regard to the treated hogs in the quarantine pasture, we find that one of those which had received but 5 c. c. of serum with the disease-producing blood died, but a positive diagnosis of hog cholera could not be made from the autopsy findings. The 2 hogs that were made sick by vaccination remained more or less unthrifty, but neither contracted hog cholera; the other 3 vaccinated hogs remained well in the quarantine pasture as well as in the Syphax exposure pen where they were placed after removal from the pasture.

EXPERIMENT XIV.—*Second experiment with first drawing of serum from immune 1274.*

The second experiment with serum from hog 1274 is incomplete, as the vaccinated hogs were not exposed to natural infection after vaccination. The results of the vaccination are of interest, however, for comparison with those of the preceding experiment in which the 2 hogs treated by the serum-simultaneous method with 10 c. c. of serum became distinctly sick. In Experiment XIV none of the 12 hogs which were given serum with disease producing blood became sick, although both of the hogs treated with the blood alone died of hog cholera. Owing to the lateness of the season and to the fact that our plans to hold vaccinated hogs for several months before exposing them had been interfered with considerably by the accidental outbreak of hog cholera in our quarantine pasture, it was decided to reserve all of the vaccinated hogs in Experiment XIV, together with their pen checks, for exposure during the summer of 1907.

TABLE 17.—*Secondary experiment with first drawing of serum from hog 1274 ("quick" immune—Syphax).*

No. of hog.	Weight.	Material injected.	Inoculation.		Remarks.
			Date.	Result.	
	Pounds.				
1938....	55	10 c. c. serum and 2 c. c. disease-producing blood of hog 1925.	Dec. 20, 1906	Remained well......	Not exposed.
1939....	50	.....do.....................	.....do.......	.....do...............	Do.
1940....	70	.....do.....................	.....do.......	.....do...............	Do.
1941....	45	.....do.....................	.....do.......	.....do...............	Do.
1942....	40	.....do.....................	.....do.......	.....do...............	Do.
1943....	40	.....do.....................	.....do.......	.....do...............	Do.
1946....	40	20 c. c. serum and 2 c. c. disease-producing blood of hog 1925.	.....do.......	.....do...............	Do.
1947....	40	.....do.....................	.....do.......	.....do...............	Do.
1948....	50	.....do.....................	.....do.......	.....do...............	Do.
1949....	40	.....do.....................	.....do.......	.....do...............	Do.
1950....	40	.....do.....................	.....do.......	.....do...............	Do.
1951....	75	.....do.....................	.....do.......	.....do...............	Do.
1954....	75	10 c. c. serum alone.........	.....do.......	.....do...............	Do.
1955....	40	.....do.....................	.....do.......	.....do...............	Do.
1956....	50	.....do.....................	.....do.......	.....do...............	Do.
1957....	60	.....do.....................	.....do.......	.....do...............	Do.
1958....	50	20 c. c. serum alone.........	.....do.......	.....do...............	Do.
1959....	80	.....do.....................	.....do.......	.....do...............	Do.
1960....	75	.....do.....................	.....do.......	.....do...............	Do.
1961....	40	.....do.....................	.....do.......	.....do...............	Do.
1944....	40	Pen check with hogs 1938 to 1943.	....	.....do...............	Do.
1945....	40	.....do.....................	....	.....do...............	Do.
1952....	40	Pen check with hogs 1946 to 1951.	....	.....do...............	Do.
1953....	40	.....do.....................	....	.....do...............	Do.
1962....	30	2 c. c. disease-producing blood of hog 1925.	Dec. 20, 1906	Sick Dec. 27, 1906; died Jan. 3, 1907.	Hemorrhages.
1963....	70	.....do.....................	.....do.......	Sick Dec. 27, 1906; died Jan. 7, 1907.	Do.
1964....	40	Pen check with hogs 1962 and 1963.	....	Sick Jan. 8, 1907; died Jan. 12, 1907.	Hemorrhages and ulcers.

Summary of results obtained with first drawing of serum from immune 1274.

Eighteen hogs were vaccinated by the serum-simultaneous method, serum in doses of 5 c. c., 10 c. c., 15 c. c., and 20 c. c. being used in conjunction with 2 c. c. of disease-producing blood. Of these 18 hogs 2 became sick; none died.

Four hogs were injected with disease-producing blood alone; all became sick; 3 died, and 1 was killed when in a moribund condition.

Eight hogs were injected with serum alone and all remained well.

Only 6 of the vaccinated hogs were later exposed to infection; 1 of these died, but without exhibiting either before death or at autopsy positive signs of hog cholera. Of 3 pen checks which were exposed at the same time as the 6 vaccinated hogs, 1 died of hog cholera, the other became sick but recovered, while the third check did not become plainly ill.

As a result of the experiments with the first drawing of serum from hog 1274, we may conclude that—

(1) The serum when given in sufficient dose will protect nonimmunes from a simultaneous injection of a fatal dose of disease-producing blood.

(2) The serum-simultaneous injections in which the largest dose of hyperimmune serum was used seemed to afford quite as complete protection from hog cholera when exposure took place three weeks after vaccination as was afforded by the injection of disease-producing blood with a smaller dose of serum.

(3) An insufficient dose of serum with disease-producing blood appeared to result in more or less permanent injury to the hogs treated in that manner.

SERUM FROM IMMUNE 1297 (SLOW METHOD).

EXPERIMENT XV.—*First drawing of serum.*

The preliminary experiment with the serum from immune 1297 shows that 5 c. c. of that serum was not sufficient to insure protection from a fatal dose of disease-producing blood administered with the serum, for, as may be seen from Table 18, hog 1742 died of hog cholera after vaccination. The other hog injected in the same manner as hog 1742, however, remained well, as did the pen check that associated with these two hogs. None of the hogs treated with doses of 10 c. c. and 15 c. c. of serum plus disease-producing blood showed any symptoms of illness, but both of the hogs that received disease-producing blood alone became sick, and one of them died. The pen check that was exposed to the hogs that were injected with disease-producing blood alone contracted hog cholera from them and died. With the exception of hogs 1743 and 1744, all of the surviving vaccinated hogs with their pen checks were placed in the pasture on October 17 to

TABLE 18.—*Preliminary experiment with first drawing of serum from hog 1297 ("slow" immune—Syphax).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1742	50	5 c. c. serum and 2 c. c. disease - producing blood of hog 1664.	Sept. 26, 1906	Sickened Oct. 6; died Oct. 9, 1906.					Hemorrhagic lesions.
1743	40	do	do	Remained well	Oct. 29, 1906	Remained well, but killed by hogs.			No pathological lesions.
1745	40	10 c. c. serum and 2 c. c. disease-producing blood of hog 1664.	do	do	Oct. 17, 1906	Remained well	Dec. 22, 1906	Remained well	
1746	35	do	do	do	do	do	do	do	
1748	45	15 c. c. serum and 2 c. c. disease-producing blood of hog 1664.	do	do	do	do	do	do	
1749	45	do	do	do	do	do	do	do	
1744	40	Pen check with hogs 1742 and 1743.		do	Oct. 29, 1906	do	Jan. 23, 1907	do	
1747	35	Pen check with hogs 1745 and 1746.		do	Oct. 17, 1906	Sickened and died Dec. 3, 1906.			Ulcers.
1750	40	Pen check with hogs 1748 and 1749.		do	do	Sickened but recovered.			
1751	40	2 c. c. disease-producing blood of hog 1664.	Sept. 26, 1906	Sickened Oct. 8; died Oct. 13, 1906.					Hemorrhagic lesions.
1752	40	do	do	Sick Oct. 8 to Nov. 5, 1906; recovered.	Dec. 4, 1906	Remained well			
1753	35	Pen check with hogs 1751 and 1752.		Sickened Oct. 18; died Nov. 1, 1906.					Hemorrhages and ulcers.

await future exposure. The accidental outbreak of hog cholera in this pasture made its appearance about the time that the hogs were placed there, and they may therefore be regarded as having been exposed to disease on October 17, or twenty-two days after vaccination. Both pen checks that were exposed at the same time with the vaccinated hogs became sick; one died, but the other recovered. None of the 4 treated pigs became sick in the pasture, and during a subsequent exposure in the Scribner exposure pen they likewise remained well. Hogs 1743 and 1744, one a vaccinated hog and the other a pen check, were placed on October 29, 1906, in a separate pasture that was used for hogs that had been made sick by vaccination or that had been removed from the exposure pen. Athough there was undoubtedly ample opportunity for these hogs to contract hog cholera in this pasture, neither of them did so, but hog 1743 was killed by other hogs. The pen check 1744 was placed in the Scribner exposure pen on January 23, 1907, to further test its immunity, with the result that it survived without showing disease.

EXPERIMENT XVI.—*Second experiment with first drawing of serum.*

In the second experiment with serum from immune 1297 the usual plan was followed. Twelve hogs were treated by the serum-simultaneous method, 6 of them being given 10 c. c. of serum, and 6, 20 c. c. of serum with 2 c. c. of disease-producing blood in each case; 4 hogs were injected with 10 c. c. of serum alone and 4 with 20 c. c. of serum alone; 2 hogs were injected with 2 c. c. of the disease-producing blood alone. Two uninoculated checks were placed in the pens with each of the lots treated by the serum-simultaneous method, and 1 was placed in the pen with the hogs that were injected with disease-producing blood alone. As may be seen from Table 19, all of the animals that were injected with serum alone or with serum and disease-producing blood combined, together with their pen checks, remained well after treatment. Both of the hogs that were injected with disease-producing blood alone contracted hog cholera, and their pen check contracted the disease from them and died of hog cholera.

In order to test further the immunity of the vaccinated hogs, half of those vaccinated by the serum-simultaneous method, together with half of those treated with serum alone, were placed in the Scribner exposure pen three weeks after vaccination. All 4 of the surviving pen checks were exposed at practically the same time. The serum-simultaneous vaccinated hogs all remained well as a result of this exposure, but 3 of the 4 hogs treated with serum alone died of hog cholera, and 3 of the 4 untreated check hogs also died.

The other treated hogs that were not exposed with the lot just described were exposed as follows: Five hogs treated by the serum-simultaneous method were exposed in the Scribner exposure pen fifty-one days after vaccination. Four hogs that were treated with

TABLE 19.—*Secondary experiment with first drawing of serum from hog 1297 ("slow" immune—Syphax).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pen exposure—Scribner.		Autopsy.
			Date.	Result.	Date.	Result.	
	Pounds.						
1836	60	10 c. c. serum and 2 c. c. disease-producing blood of hog 1631.	Nov. 1, 1906	Remained well	Nov. 22, 1906	Remained well	
1837	65	do	do	do	do	do	
1838	55	do	do	do	do	do	
1839	45	do	do	do	Dec. 22, 1906	do	
1840	70	do	do	do	do	do	
1841	70	do	do	do		Not exposed	
1844	60	20 c. c. serum and 2 c. c. disease-producing blood of hog 1631.	do	do	Nov. 22, 1906	Remained well	
1845	60	do	do	do	do	do	
1846	60	do	do	do	do	do	
1847	60	do	do	do	Dec. 22, 1906	do	
1848	60	do	do	do	do	do	
1849	60	do	do	do	do	do	
1852	55	10 c. c. serum alone	do	do	Jan. 31, 1907	Died Feb. 19, 1907	Hemorrhages and ulcers.
1853	75	do	do	do	Nov. 22, 1906	Died Dec. 6, 1906	Hemorrhagic lesions.
1854	55	do	do	do	Jan. 31, 1907	Remained well	
1855	40	do	do	do	Nov. 22, 1906	Died Dec. 9, 1906	Do.
1856	45	20 c. c. serum alone	do	do	Jan. 31, 1907	Died Feb. 22, 1907	Do.
1857	60	do	do	do	do	Died Feb. 11, 1907	Do.
1858	45	do	do	do	Nov. 22, 1906	Remained well	
1859	60	do	do	do	do	Died Dec. 9, 1906	Do.
1842	40	Pen check with hogs 1836 to 1841		do	Nov. 17, 1906	Died Dec. 1, 1906	Do.
1843	30	do		do	Nov. 22, 1906	Died Dec. 2, 1906	Do.
1850	50	Pen check with hogs 1844 to 1849		do	do	Died Dec. 4, 1906	Do.
1851	50	do		do	do	Remained well	
1867	50	2 c. c. disease-producing blood of hog 1631.	Nov. 1, 1906	Sick Nov. 7; died Nov. 11, 1906.			Do.
1868	50	do		Sick Nov. 7; killed Nov. 14, 1906.			Do.
1869	40	Pen check with hogs 1867 and 1868		Sick Nov. 15; died Nov. 20, 1906.			Do.
1992	50				Dec. 27, 1906	Sickened; died Jan. 16, 1907	Do.
1993	30				do	Sickened; died Jan. 11, 1907	Do.
1994	40				do	Sickened; died Jan. 8, 1907	Do.
1995	40				do	Sickened; died Jan. 11, 1907	Do.
1996	35				do	Sickened; died Jan. 14, 1907	Do.
1997	35				do	Sickened; died Jan. 16, 1907	Do.
1998	40				do	Sickened; died Jan. 18, 1907	Do.

serum alone were exposed in the same pen twelve weeks after vaccination. The virulence of the disease to which the serum-simultaneous treated hogs were subjected is shown by the fact that 7 check hogs (1992–1998, Table 19) placed in the exposure pen five days later all died of hog cholera, but notwithstanding this very severe test, all of the serum-simultaneous vaccinated hogs remained well. Of the 4 hogs vaccinated with serum alone and exposed twelve weeks after treatment 3 died, as was to be expected, since the hogs treated similarly and exposed only three weeks after treatment did not show any appreciable degree of resisting power.

Summary of results obtained with serum from immune 1297.

Eighteen hogs were vaccinated by the serum-simultaneous method, the serum being used in doses of from 5 c. c. to 20 c. c. Only 1 of these hogs died from the treatment, and this hog (1742) received but 5 c. c. of the serum. Four hogs were injected with the same dose of the same disease-producing blood as was given the serum-simultaneous treated hogs, and as a result all became sick and 3 died. Of 6 pen checks exposed to the serum-simultaneous treated hogs after vaccination all remained well, although both of the checks exposed to hogs treated with diseased blood alone contracted hog cholera and died.

In regard to immunity in the treated hogs subsequent to vaccination it is seen that of the 16 serum simultaneous treated hogs all remained well when exposed from three to seven weeks after vaccination. Of 8 hogs treated with serum alone and exposed to hog cholera from three to twelve weeks after vaccination we find that 6 died of hog cholera, while of 4 checks not inoculated and exposed to the same infection 3 died.

With regard to the experiments with the first drawing of serum from immune 1297, the following conclusions may be drawn:

(1) When administered in sufficient dose this serum will completely protect hogs from an otherwise fatal dose of disease-producing blood given simultaneously with the serum.

(2) The immunity produced by a serum-simultaneous vaccination remained quite firm for at least seven weeks.

(3) This immunity was quite as firm in the hogs that received 20 c. c. of serum with disease-producing blood as in those that received only 10 c. c.

(4) It is not necessary for hogs to show visible symptoms of illness after vaccination in order to secure immunity that will last at least seven weeks.

(5) The immunity in serum-simultaneous vaccinated hogs was not due to serum alone, as shown by the death of animals injected with serum alone when exposed to hog cholera.

TABLE 20.—*Preliminary experiment with first drawing of serum from hog 1310 ("slow" immune—Syphax).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1671	45	5 c. c. serum and 2 c. c. disease-producing blood of hog 1641.	Sept. 8, 1906	Sick Sept. 14; died Sept. 24, 1906.					Hemorrhages and ulcers.
1672	45	do	do	Sick Sept. 15 to 26, 1906; recovered.			Oct. 29, 1906	Remained well	
1674	50	10 c. c. serum and 2 c. c. disease-producing blood of hog 1641.	do	Sick Sept. 14; died Oct. 2, 1906.					Do.
1675	50	do	do	Sick Sept. 15 to 21, 1906; recovered.	Oct. 15, 1906	Remained well			
1677	55	15 c. c. serum and 2 c. c. disease-producing blood of hog 1641.	do	Remained well	do	do	Dec. 22, 1906	Remained well	
1678	50	do	do	do	do	do	do	do	
1673	35	Pen check with hogs 1671 and 1672.		Sick Oct. 9; died Oct. 13, 1906.					Intestinal ulcers.
1676	30	Pen check with hogs 1674 and 1675.		Sick Sept. 21 to 25, 1906; recovered.	Oct. 15, 1906	Killed by other hogs			No autopsy.
1679	45	Pen check with hogs 1677 and 1678.		Remained well	do	Died Nov. 2, 1906			Hemorrhagic lesions.
1680	50	2 c. c. disease-producing blood of hog 1641.	Sept. 8, 1906	Sick Sept. 15; died Sept. 23, 1906.					Hemorrhages and ulcers.
1681	50	do	do	Sick Sept. 15; died Sept. 22, 1906.					Do.
1682	40	Pen check with hogs 1680 and 1681.		Sick Sept. 25; died Sept. 28, 1906.					Do.

(6) Hogs immunized with serum prepared from one strain of disease (Syphax) may be expected to resist infection of the same nature from an entirely different source (Scribner).

(7) Hogs vaccinated by the serum-simultaneous method, if not made sick by the treatment, will not communicate disease to other hogs.

SERUM FROM IMMUNE 1310 (SLOW METHOD).

EXPERIMENT XVII.—*Preliminary experiment with first drawing of serum.*

In this experiment only the serum-simultaneous method of vaccination was used, and Table 20 shows the results. Six hogs were vaccinated by the serum-simultaneous method, doses of 5 c. c., 10 c. c., and 15 c. c. of serum being used. Of the 4 hogs injected with less than 15 c. c. of serum all became sick and 2 died, and the 2 pen checks contracted hog cholera from them. The 2 hogs that were injected with 15 c. c. of serum in combination with the disease-producing blood remained well, while the 2 injected with disease-producing blood alone died and communicated disease to their pen check.

Three of the surviving vaccinated hogs in this experiment were exposed to hog cholera in the quarantine pasture and 1 in the Syphax exposure pen. It was to be expected that the hogs that had been sick would be subsequently immune, and this was found to be the case.

The chief interest in the exposure of these hogs lay in the behavior of the hogs that received 15 c. c. of serum with disease-producing blood and which did not become ill as a result of vaccination. These 2 hogs (1677 and 1678) were exposed to hog cholera in the pasture thirty-seven days after vaccination. They did not become sick as a result of this exposure, although their pen check which was exposed with them contracted hog cholera and died. A later exposure of these 2 hogs in the Scribner exposure pen three and one-half months after vaccination proved them to be still immune.

EXPERIMENT XVIII.—*Second experiment with first drawing of serum.*

In this experiment, through an error, doses of 10 c. c. and 20 c. c. of serum were used with disease-producing blood, although the preliminary experiment had shown that 10 c. c. of this serum was not sufficient to protect hogs from a fatal dose of disease-producing blood. It appears, however, that even the dose of 10 c. c. of serum may have increased the resisting power of the vaccinated hogs somewhat. Six hogs were injected with 10 c. c. of serum plus disease-producing blood, 6 with 20 c. c. of serum plus disease-producing blood, 4 with 10 c. c. of serum alone, 4 with 20 c. c. of serum alone, and 2 with 2 c. c. of disease-producing blood alone. Two pen checks were placed with each lot of serum-simultaneous treated hogs and one with the hogs injected with disease-producing blood alone. Table 21 shows that 4 of the 6 hogs treated with 10 c. c. of serum plus disease-producing

TABLE 21.—*Secondary experiment with first drawing of serum from hog 1310 ("slow" immune—Syphax).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pen exposure—Scribner.		Autopsy.
			Date.	Result.	Date.	Result.	
	Pounds.						
1896	55	10 c. c. serum and 2 c. c. disease-producing blood of hog 1891.	Nov. 23, 1906	Sick Nov. 30; died Dec. 2, 1906.			Hemorrhagic lesions.
1897	50	do	do	Remained well	[a]Dec. 27, 1906	Remained well	
1898	50	do	do	Sick Nov. 30; died Dec. 4, 1906.			Lesions not marked.
1899	50	do	do	do			Do.
1900	50	do	do	Sick Nov. 30; died Dec. 5, 1906.			Hemorrhages and ulcers.
1901	50	do	do	Remained well	[a]Dec. 27, 1906	Remained well	
1904	80	20 c. c. serum and 2 c. c. disease-producing blood of hog 1891.	do	do	do.[a]	do	
1905	80	do	do	do	Feb. 4.1907	do	
1906	60	do	do	do	do	do	
1907	60	do	do	do	[a]Dec. 27, 1906	do	
1908	40	do	do	do	do.[a]	do	
1909	60	do	do	do	Feb. 4, 1907	do	
1912	80	10 c. c. serum alone	do	do	Dec. 11, 1906	Died Jan. 1, 1907	Hemorrhagic lesions.
1913	80	do	do	do	do	Died Dec. 24, 1906	Hemorrhages and ulcers.
1914	80	do	do	do	Jan. 31, 1907	Died Feb. 15, 1907	Do.
1915	70	do	do	do	do	Died Feb. 19, 1907	Do.
1916	80	20 c. c. serum alone	do	do	Dec. 11, 1906	Remained well	
1917	80	do	do	do	do	Died Jan. 1, 1907	No autopsy.
1918	80	do	do	do	Jan. 31, 1907	Remained well	
1919	80	do	do	do	do	Died Feb. 15, 1907	Hemorrhagic lesions.
1902	50	Pen check with hogs 1896 to 1901		do	Dec. 27, 1906	Died Jan. 14, 1907	Do.
1903	40	do		do	do	Died Jan. 13, 1907	Do.
1910	40	Pen check with hogs 1904 to 1909		do	Dec. 11, 1906	Died Dec. 21, 1906	Hemorrhages and ulcers.
1911	45	do		do	do	Died Dec. 30, 1906	Do.
1929	45	2 c. c. disease-producing blood of hog 1891.	Nov. 23, 1906	Sick Nov. 29; died Dec. 2, 1906.			Hemorrhagic lesions.
1930	45	do	do	Sick Nov. 29; died Dec. 3, 1906.			Do.
1931	30	Pen check with hogs 1929 and 1930		Sick Dec. 8; died Dec. 19, 1906.			Hemorrhages and ulcers.
2003	40				Feb. 4, 1907	Died Feb. 9, 1907	Do.
2004	40				do	Died Feb. 14, 1907	Do.
2005	40				do	Died Feb. 16, 1907	Do.

[a] Compare records of check hogs 1992, 1993, etc., Table 19.

blood died from the treatment, but, strange to say, the checks in the same pen did not contract the disease from them; the hogs that received 20 c. c. of serum with disease-producing blood all remained well, as did those injected with serum alone. The 2 hogs injected with disease-producing blood alone died of hog cholera, as did the check exposed in the pen with them.

The surviving hogs from the protective inoculations, including 4 pen checks (1902, 1903, 1910, and 1911) which had not been sick, were exposed to hog cholera at different lengths of time after vaccination.

Of the hogs treated with serum alone, 2 that received 10 c. c. and 2 that received 20 c. c. of serum were placed in the Scribner exposure pen eighteen days after vaccination with 2 of the pen checks; both of the checks and 3 of the 4 serum-treated pigs died of hog cholera. The surviving treated hog was one that had received 20 c. c. of serum. The 4 remaining hogs treated with serum alone were exposed first sixty-eight days after vaccination, and 3 out of 4 died of hog cholera, the surviving hog being again one of those that received 20 c. c. of serum, though it is very doubtful whether the resistance of this hog can be properly attributed to the previous serum injection. The behavior of the serum-simultaneous hogs after exposure to hog cholera was quite different from that of the hogs treated with serum alone.

It will be remembered that 12 hogs were vaccinated by the serum-simultaneous method, and of these 4 died as a result of vaccination, these having received only 10 c. c. of serum with the disease-producing blood. The 2 surviving hogs that received 10 c. c. of serum plus disease-producing blood were placed in the Scribner exposure pen with 3 of those treated with 20 c. c. of serum plus disease-producing blood thirty-four days after vaccination; all of these hogs remained well, although the 2 checks (1902 and 1903) exposed at the same time died of hog cholera. The 3 remaining hogs treated with 20 c. c. of serum plus disease-producing blood were first exposed to hog cholera by being placed in the Scribner exposure pen seventy-two days after vaccination. All of them remained well, although unvaccinated check hogs 2003, 2004, and 2005, subjected to the same exposure died of hog cholera.

Summary of experiments with first drawing of serum from immune 1810.

Results of vaccination.—Eighteen hogs were vaccinated by the serum-simultaneous method; of these 10 received 10 c. c. or less of serum, while the remaining 8 received 15 c. c. or more of serum. Eight out of the first 10 became sick, and 6 died, as a result of vaccination, while none of the 8 hogs that received larger doses of serum became sick. Four hogs that were injected with disease-producing blood alone died of hog cholera as a result of the injection. The 8 hogs that were injected with serum alone as usual remained well.

All pen checks with vaccinated hogs remained well, notwithstanding the fact that some were exposed to hogs that died as a result of vaccination.

Results of exposure to hog cholera.—Twelve hogs treated by the serum-simultaneous method were exposed to hog cholera after vaccination, some being exposed after an interval of twenty-four days while others were not exposed until approximately two and one-half months after vaccination. Of these hogs only 2 had shown symptoms of sickness after vaccination. None of the 12 became sick as a result of exposure. Eight hogs that had been treated with serum alone were exposed to hog cholera, 4 being exposed eighteen days after vaccination, and 4 two months and eighteen days after vaccination; 6 of these died of hog cholera. Five unvaccinated hogs were exposed with the treated hogs as checks, and all of these died of hog cholera.

From these experiments we may conclude that—

(1) The serum from hog 1310, first drawing, will, when given in sufficient dose, protect hogs from a fatal dose of disease-producing blood administered simultaneously with the serum.

(2) This simultaneous vaccination confers on the treated hogs an immunity which lasts for at least two and one-half months.

(3) The immunity in hogs which showed no symptoms after vaccination seems to be quite as firm as in those that were made visibly ill.

(4) Serum alone did not confer a satisfactory immunity for even three weeks in the dose used.

(5) The immunity in serum-simultaneous hogs was not due to the action of the serum alone.

(6) Check hogs exposed to hogs which became sick as a result of vaccination contracted disease from them in some cases.

PRODUCTION OF A PROTECTIVE SERUM BY USING A REDUCED DOSE OF DISEASED BLOOD.

The hogs in the preceding experiments that were hyperimmunized by the "quick method" all received a dose of disease-producing blood in the proportion of 1,000 c. c. of blood to 100 pounds of body. We have carried out only one experiment with serum from an immune hyperimmunized with a smaller dose of disease-producing blood. This hog (1401) received only 500 c. c. of disease-producing blood for hyperimmunization. The history of hog 1401, as well as the experiments carried out with serum from that hog, are described below.

Experiment XIX.—*Serum from immune 1401.*

Hog 1401 is one of those that was vaccinated by the serum-simultaneous method in the experiments of 1905, and its detailed history is as follows:

Hog 1401 weighed 60 pounds December 2, 1905, and on this date, together with other hogs, was injected simultaneously with disease-producing blood and 10 c. c. of serum from immune 1234 (see p. 11). No symptoms of sickness followed this injection, and the hog was exposed to disease on December 27, 1905. Hog 1401 again remained well and was not further exposed until September 3, 1906, when it was injected subcutaneously with 500 c. c. of Scribner disease-producing blood. The weight of the hog at this time was approximately 100 pounds. No visible disturbance of health followed this injection. On September 24, 1906, just three weeks after the injection of disease-producing blood, hog 1401 was bled in order to secure serum for experimental purposes. This hog may be classed with the Scribner quick immunes, though the dose of serum used in proportion to the body weight of the immune is only half of that used on the other Scribner quick immunes.

Unfortunately, we were not able to carry out as extensive experiments with this serum as was desirable, but the number of animals available for experimental purposes and the requirements of other experiments in the way of pens and hogs made it impossible to do more than make a preliminary test of the potency of the serum from immune 1401.

The tests of this serum were made in the usual manner, the serum being used in doses of 5 c. c., 10 c. c., and 15 c. c., given simultaneously with a fatal dose of disease-producing blood. Table 22 shows the results of these injections. Both of the hogs injected with only 5 c. c. of serum became sick and 1 died, and they also communicated disease to their pen check, hog 1814. One of the 2 hogs that were injected with 10 c. c. of serum plus disease-producing blood became slightly sick but recovered, while the other remained well; the pen check in this pen contracted hog cholera. Neither of the hogs that received 15 c. c. of serum with the disease-producing blood showed any symptoms of illness following vaccination, and their pen check likewise remained well. Both of the hogs that were injected with disease-producing blood alone died of hog cholera and communicated the disease to their pen check, hog 1823.

It will thus be seen that of 6 hogs inoculated simultaneously with serum and diseased blood, 3 became sick but only 1 died, and this one received the smallest dose (5 c. c.) of serum. Four of the 5 surviving vaccinated hogs were later exposed to hog cholera to test the duration of the immunity conferred by vaccination. Two of these hogs were placed in the Scribner exposure pen on November 17, 1906, thirty days after vaccination; the surviving pen check, hog 1820, was exposed at the same time. The check died, but both of the treated hogs remained well. The 2 other vaccinated hogs were first exposed to hog cholera three and one-half months after vaccination. They both remained well, although unprotected hogs exposed at the same time died of hog cholera.

Although we have hyperimmunized only 1 hog by the quick method with a dose of disease-producing blood equal to 500 c. c. per 100 pounds of body weight, the results obtained with this serum are such that there is good reason to believe that this reduced dose might be sufficient to produce a satisfactory serum. Owing to reasons already stated, we have not as yet been able to decide this point, but from what has been done we may conclude that (1) the serum of hog 1401 is as potent as that of some other immunes injected with larger doses of disease-producing blood, but that it is not equal in potency to that from the majority of immunes which received twice as much disease-producing blood; (2) when given in sufficient dose this serum will protect perfectly from a fatal dose of disease-producing blood administered simultaneously with the serum; (3) the immunity produced by the serum-simultaneous injections lasted at least three and one-half months, even though the treated hogs showed no signs of reaction after injection; (4) it appears possible that the injection of serum did not lower the infectiousness of the disease to as great an extent as other sera from immunes that were given larger doses of diseased blood,

TABLE 22.—*Preliminary experiment with first drawing of serum from hog 1401 (500 c. c. "quick" immune—Scribner).*

No of hog.	Weight.	Material injected.	Inoculation.		Pen exposure—Scribner.		Autopsy.
			Date.	Result.	Date.	Result.	
	Pounds.						
1812....	40	5 c. c. serum and 2 c. c. disease-producing blood of hog 1774.	Oct. 18, 1906	Sick Oct. 27; died Oct. 29, 1906.	....	....	Pleuritis; no other marked lesions.
1813....	50	.....do..........	.....do.......	Sick Oct. 10, 1906; recovered	....	Not exposed............	
1815....	45	10 c. c. serum and 2 c. c. disease-producing blood of hog 1774.	.....do.......	Slightly sick Nov. 3, 1906; recovered.	Nov. 17, 1906	Remained well............	
1816....	50	.....do..........	.....do.......	Remained well..........	.....do.......	.....do..........	
1818....	40	15 c. c. serum and 2 c. c. disease-producing blood of hog 1774.	.....do.......	.....do..........	[a] Jan. 31, 1907	.....do..........	
1819....	50	.....do..........	.....do.......	.....do..........	.....do.......	.....do..........	
1814....	35	Pen check with hogs 1812 and 1813...	....	Sick Nov. 3; died Nov. 14, 1906.	....	....	Hemorrhages.
1817....	45	Pen check with hogs 1815 and 1816...	....	Sick Nov. 12; died Nov. 21, 1906.	....	....	Do.
1820....	35	Pen check with hogs 1818 and 1819...	....	Remained well..........	Nov. 17, 1906	Died Dec. 6, 1906..........	Hemorrhages and ulcers.
1821....	40	2 c. c. disease-producing blood of hog 1774.	Oct. 18, 1906	Sick Oct. 27; died Nov. 1, 1906.	....	....	Hemorrhages.
1822....	50	.....do..........	.....do.......	Sick Oct. 27; died Nov. 7, 1906.	....	....	Do.
1823....	40	Pen check with hogs 1821 and 1822...	....	Sick Nov. 3; died Nov. 23, 1906.	....	....	Do.

[a] See Table 21 for record of hogs 2003, 2004, 2005, checks exposed in same pen on same date.

for pen check 1817 contracted hog cholera from exposure to hogs 1815 and 1816, although only one of these became slightly sick. It will be remembered that as a rule the pen checks with serum-simultaneous vaccinated hogs remained well, and that when the vaccinated hogs were made desperately sick by the treatment the pen checks occasionally contracted disease.

EXPERIMENTS WITH SERUM FROM NONHYPERIMMUNIZED IMMUNES.

In view of the very marked protective power possessed by the serum of hog 1401, as shown in the experiment just described, it was considered advisable to test the serum from at least 2 immunes that had not been given any injections of diseased blood for the purpose of hyperimmunization. Previous experiments of this character had not revealed any noticeable protective power in the blood of normal immunes, but nevertheless for the sake of comparison it was deemed best to repeat those tests. The history of the 2 immunes selected for this work is given in brief in connection with the tests of serum from each of them described below.

EXPERIMENT XX.—*Serum from nonhyperimmunized immune 1424.*

This hog was vaccinated by the serum-simultaneous method in the 1905 experiments, as noted in Table 3 of this paper. The detailed history is as follows: On December 16, 1905, hog 1424, which weighed at that time 45 pounds, was injected simultaneously with 2 c. c. of disease-producing blood and 10 c. c. of hyperimmune serum from hog 1234. No visible symptoms of illness followed this injection, although the same diseased blood caused the death of all unprotected hogs that were injected at the same time. (See Table 3.) On January 9, 1906, this hog was exposed to virulent disease by being placed in the exposure pen. This exposure was without effect.

On October 8, 1906, blood was drawn from hog 1424, and after being defibrinated and mixed with the carbolic acid solution in the usual manner it was used in the following experiment.

Two hogs were injected with 10 c. c. each of serum from hog 1424 plus disease-producing blood, and 2 with 20 c. c. each of serum plus disease-producing blood. One untreated healthy hog was placed in the pen with each lot in the usual manner, and 2 hogs were inoculated with disease-producing blood alone, a check being placed in the pen with these also. The manner of carrying out this experiment and the results obtained are very well shown in Table 23.

From Table 23 it may be seen that the 4 hogs that were injected with disease-producing blood and serum became sick. It will be seen, however, that only 2 of these died, while both of those that received disease-producing blood alone died. It may also be of significance, though not necessarily so, that both of the vaccinated hogs that died showed symptoms of disease somewhat later than the hogs that received no serum, and they also lived a longer time. From the small number of tests carried out it can not be stated with complete assurance that this greater resisting power on the part of the vaccinated hogs was due to the influence of the immune serum.

EXPERIMENTS WITH SERUM FROM NONHYPERIMMUNIZED IMMUNE 1295.

In order to test further the value of nonhyperimmunized immune serum, the blood of another immune was used in the following-described experiment:

Immune hog 1295 was selected for comparison with hog 1424 because the latter had never shown any symptoms of illness after exposure to hog cholera, while the former had recovered from a mild attack of that disease. It might be supposed, therefore, that hog 1424 possessed natural immunity, while hog 1295 probably acquired immunity through a mild attack of hog cholera. This supposition in regard to hog 1424 is not of necessity true, however, because our experiments have shown that susceptible hogs rarely become sick after vaccination, and it is quite probable that hog 1424 acquired immunity from vaccination. This hog 1295 was first exposed to hog cholera on September 12, 1905. At that time the hog weighed 100 pounds. The exposure to disease was made by the subcutaneous injection of disease-producing blood. Following this injection hog 1295 became

TABLE 23.—*Experiment with serum from hog 1424 (nonhyperimmunized immune).*

No. of hog.	Weight.	Material injected.	Inoculation.		Pen exposure—Scribner.		Autopsy.
			Date.	Result.	Date.	Result.	
	Pounds.						
1801....	40	10 c. c. serum and 2 c. c. disease-producing blood of hog 1711.	Oct. 10, 1906	Sick Oct. 17; died Nov. 4, 1906.	....	....	Hog cholera.
1802....	45	.....do..............................	.....do.......	Sick Oct. 18, 1906; recovered.	Nov. 17, 1906	Remained well............	
1804....	60	20 c. c. serum and 2 c. c. disease-producing blood of hog 1711.	.....do.......	Slightly sick; recovered	.....do.......	.....do..................	
1805....	35	.....do..............................	.....do.......	Sick Oct. 19; died Dec. 6, 1906.	....	....	Do.
1803....	35	Pen check with hogs 1801 and 1802..	....	Sick Nov. 5, 1906; died Jan. 8, 1907.	....	....	No marked lesions.
1806....	35	Pen check with hogs 1804 and 1805..	....	Sick Nov. 1; died Dec. 1, 1906.	....	....	Hog cholera.
1807....	50	2 c. c. disease-producing blood of hog 1711.	Oct. 10, 1906	Sick Oct. 15; died Oct. 28, 1906.	....	....	Do.
1808....	35	.....do..............................	.....do.......	Sick Oct. 16; died Oct. 29, 1906.	....	....	Do.
1809....	30	Pen check with hogs 1807 and 1808..	....	Sick Oct. 26; died Oct. 31, 1906.	....	....	Do.

distinctly though not desperately sick, showing the usual symptoms of a rather mild attack of hog cholera. After recovery from this illness hog 1295 was placed in the exposure pen, but did not become sick. This hog was finally removed from the exposure pen, but was not again exposed to hog cholera. Blood was drawn from hog 1295 on November 22, 1906, and after being prepared in the usual manner was used in the experiment next described.

EXPERIMENT XXI.—*Serum from nonhyperimmunized immune 1295.*

This experiment was modeled directly after the preliminary experiments with the hyperimmune serum, the serum-simultaneous method only being used, as previous experiments had shown that all of the hyperimmunized hogs furnished serum that would protect, when given in sufficient dose, from a simultaneous injection of disease-producing blood, and it was evident that a failure to protect from a simultaneous injection of such blood would certainly render unnecessary an experiment to determine the duration of immunity conferred by serum alone.

TABLE 24.—*Experiment with serum from hog 1295 (nonhyperimmunized immune).*

No. of hog.	Weight.	Material injected.	Inoculation.		Autopsy.
			Date.	Result.	
	Pounds.				
1920....	45	5 c. c. serum and 2 c. c. disease-producing blood of hog 1891.	Nov. 23, 1906	Sick Nov. 29; died Dec. 1, 1906.	Hemorrhagic lesions.
1921....	45	.....do.	.....do.......	Sick Nov. 29; died Dec. 2, 1906.	Do.
1922....	30	Pen check with hogs 1920 and 1921.		Sick Dec. 8; died Dec. 16, 1906.	Hemorrhages and ulcers.
1923....	45	10 c. c. serum and 2 c. c. disease-producing blood of hog 1891.	Nov. 23, 1906	Sick Nov. 29; died Dec. 2, 1906.	Hemorrhagic lesions.
1924....	45	.....do.	.....do.......	Sick Nov. 29, 1906; died	Do.
1925....	35	Pen check with hogs 1923 and 1924.		Sick Dec. 13; killed Dec. 20, 1906.	No marked lesions.
1926....	40	15 c. c. serum and 2 c. c. diseased blood of hog 1891.	Nov. 23, 1906	Sick Nov. 29; died Dec. 1, 1906.	Hemorrhagic lesions.
1927....	40	.....do.	.....do.......	Sick Nov. 29; died Dec. 3, 1906.	Do.
1928....	40	Pen check with hogs 1926 and 1927.		Sick Dec. 5; died Dec. 9, 1906.	Hemorrhages and ulcers.
1929....	50	2 c. c. disease-producing blood of hog 1891.	Nov. 23, 1906	Sick Nov. 29; died Dec. 2, 1906.	Hemorrhagic lesions.
1930....	40	.....do.	.....do.......	Sick Nov. 29; died Dec. 3, 1906.	Hemorrhages and ulcers.
1931....	35	Pen check with hogs 1929 and 1930.		Sick Dec. 8; died Dec. 19, 1906.	Do.

Table 24 shows without question the lack of potency of the serum from hog 1295. Doses of 15 c. c. of serum did not prove to be any more potent than doses of 5 c. c., and every hog in this experiment died of hog cholera, the disease being communicated to the pen checks in all cases. It does not appear that the serum, even in the largest doses, exercised any retarding influence upon the incubation period or upon the course of the disease once it had appeared.

Summary of results obtained with serum from nonhyperimmunized immunes.

Serum from 2 immunes was used in doses of from 5 c. c. to 20 c. c., and this serum was injected into nonimmunes simultaneously with a fatal dose of disease-producing blood. Ten were treated by this process; all contracted hog cholera, and 8 died of that disease. Of 4 hogs injected with disease-producing blood alone, all died of hog cholera. Five checks were placed in the pens with the vaccinated hogs, and all contracted disease from them and died. The 2 pen checks exposed in the pen with the hogs that received disease-producing blood only also died of hog cholera.

From the results stated above it will be seen that (1) the protection afforded to nonimmune hogs by the injection of serum from nonhyperimmunized immunes is very slight as compared with that afforded by hyperimmune serum; (2) even in doses of 20 c. c. the protection afforded was not sufficient to prevent the death of 1 of the 2 animals that received that dose; (3) the contagiousness of the disease is not noticeably lessened by the injection of serum from a nonhyperimmunized immune; and (4) the serum from nonhyperimmunized immunes is not potent enough to render its use practicable in combating hog cholera.

EXPERIMENTS WITH SUCKLING PIGS.

The following experiments with young pigs were carried out for the purpose of determining whether very young pigs would react to vaccination with immune serum in the same manner as the larger shoats. It was desirable to determine also whether very much smaller doses of serum might not be used on the small pigs, thus effecting a considerable saving in the cost of vaccination. The plan adopted was to vaccinate part of a litter of pigs and leave part unvaccinated, so that when the time came for testing the immunity of the vaccinated pigs we would have a sufficient number of checks for exposure along with the vaccinated pigs, and additional information regarding the danger of hog cholera being transmitted through the agency of vaccinated hogs would also be secured.

TABLE 25.—*First experiment with suckling pigs—first drawing of serum from hog 1383.*

No. of hog.	Weight.	Material injected.	Inoculation.		Exposure—Scribner.		Autopsy.
			Date.	Result.	Date.	Result.	
	Pounds.						
1724		Sow—40 c. c. serum	Oct. 5, 1906	Remained well			
1725	5	2 c. c. serum and 0.25 c. c. disease-producing blood of hog 1680.	Sept. 21, 1906	Sickened Oct. 2, 1906; recovered.		Not exposed	
1726	5	do	do	Sick Oct. 2; died Oct. 7, 1906.			Hemorrhagic lesions.
1727	5	do	do	Sick Oct. 2, 1906; recovered.	Feb. 20, 1907	Remained well	
1728	4½	Uninoculated pen check		Remained well		Not exposed	
1729	4	do		do	Feb. 20, 1907	Died Mar. 10, 1907	Hemorrhages and ulcers.
1730	40	2 c. c. disease-producing blood of hog 1680.	Oct. 5, 1906	Sick Sept. 27; died Oct. 2, 1906.			Hemorrhages.
1731	50	do	do	Sick Sept. 27; killed Sept. 29, 1906.			Do.
1732	40	Pen check with hogs 1730 and 1731		Sick Oct. 4; died Oct. 13, 1906.			Hemorrhages and ulcers.

EXPERIMENT XXII.—*Serum-simultaneous vaccination of suckling pigs, using serum from immune 1383.*

The 5 suckling pigs used in this experiment were 10 days old at the time of vaccination and all were vigorous and healthy. Two older pigs (1730 and 1731) were injected at the same time as the suckling pigs with disease-producing blood alone, in order to test the virulence of the blood. By referring to Table 25 the method of carrying out the experiment may be best understood.

Three of the suckling pigs were given 2 c. c. each of serum with 0.25 c. c. of disease-producing blood subcutaneously; the remaining 2 were not treated, but the entire litter was left together, the sow being given 40 c. c. of serum as a protection against possible infection from the vaccinated pigs. No pigs were injected with 0.25 c. c. of disease-producing blood alone, but the death of pig 1726 and the sickness of 1725, in spite of the injection of the serum, indicate that 0.25 c. c. of the disease-producing blood used in this experiment would probably have been sufficient to destroy all of the injected pigs if the serum had not been used. The virulence of the disease-producing blood in the usual dose, 2 c. c., is shown by the records of hogs 1730 and 1731, and the contagiousness of the disease is proven by the sickness and death of uninoculated hog 1732, exposed in the pen with hogs 1730 and 1731. These 3 hogs—1730, 1731, and 1732—were of course placed in a pen to themselves and did not at any time associate with the other hogs in this experiment. The low degree of contagiousness of the disease following vaccination, which has been remarked upon in connection with other experiments already described, is again well shown in this experiment, where the uninoculated suckling pigs remained well even though they associated with pig 1726, which died from vaccination.

The 4 surviving pigs—1725, 1727, 1728, and 1729—were with the mother transferred to a pasture that was free from hog cholera. All remained well, and approximately four months after vaccination they were weaned. Shortly after this, pigs 1725 and 1728 became sick and died. Neither showed lesions of hog cholera, and as there is nothing to show that disease had ever been introduced into this pasture, we must consider the death of these pigs to have been due to some other cause, the exact nature of which we were not able to determine. For this reason Table 25 does not show the history of pigs 1725 and 1728 subsequent to vaccination. The remaining pigs of this litter, 1727 and 1729, one a vaccinated pig and the other a check, were placed in the Scribner exposure pen on February 20, 1907, just five months after pig 1727 had been vaccinated. As a result of this exposure the check (1729) sickened and died on March 10, 1907, while the treated pig (1727) remained well. The results of this exposure furnish additional proof that the death of pigs 1725 and 1728 in the pasture before exposure was not due to hog cholera, for, upon undoubted exposure to that disease, vaccinated pig 1727, treated in the same manner as pig 1725, remained well, while the check (1729) died, thus indicating that had the disease in the pasture been hog cholera the vaccinated pig (1725) would not have succumbed, while pig 1729, which was later found to be susceptible, would have contracted disease at that time.

Owing to the loss of 1 of the pigs of this litter from vaccination and of 2 others through an intercurrent disease, as just explained, this experiment does not throw very much light upon the feasibility of vaccinating suckling pigs. It does indicate, however, that the serum of hog 1383, in doses of 2 c. c., is sufficient in most cases to protect pigs weighing 5 pounds from a fatal dose of disease-producing blood administered simultaneously with the serum. It appears also that the serum exerted decided influence in lessening the contagiousness of the disease. The weight that should be attached to the death of check pig 1729 and the survival of vaccinated pig 1727 when exposed together to hog cholera can only be properly considered in connection with the behavior of other pigs under similar conditions and treated in a similar manner.

TABLE 26.—*Second experiment with suckling pigs—first drawing of serum from hog 1313.*

No. of hog.	Weight.	Material injected.	Inoculation.		Exposure—Scribner.		Autopsy.
			Date.	Result.	Date.	Result.	
	Pounds.						
1824		Sow—not treated					
1825	9	3 c. c. serum and 0.25 c. c. disease-producing blood of hog 1774.	Oct. 18, 1906	Slightly sick Nov. 1, 1906; recovered.	Feb. 20, 1907	Remained well	
1826	9	do	do	do	do	do	
1827	9	4 c. c. serum and 0.25 c. c. disease-producing blood of hog 1774.	do	do	do	do	
1828	9	do	do	do	do	do	
1829	9	Not injected		Remained well	do	Died Mar. 7, 1907	Hemorrhages.
1830	8	do		do	do	Died Mar. 10, 1907	Hemorrhages and ulcers.
1831	8	do		do	do	Died Mar. 7, 1907	Hemorrhages.
1821	40	2 c. c. disease-producing blood of hog 1774.	Oct. 18, 1906	Sick Oct. 27; died Nov. 1, 1906.			Do.
1822	50	do	do	Sick Oct. 27; died Nov. 7, 1906.			Do.
1823	40	Pen check with hogs 1821 and 1822		Sick Nov. 3; died Nov. 23, 1906.			Do.

EXPERIMENT XXIII.—*Serum-simultaneous vaccination of suckling pigs, using serum from immune 1313.* [a]

Seven suckling pigs, all of the same litter and about 2 weeks old, were used in this experiment. The weight of these pigs was approximately 9 pounds each, with the exception of 2 of those reserved as checks, which were a very little lighter in weight. Of the vaccinated pigs, 2 were given 3 c. c. of serum from hog 1313 and 2 were given 4 c. c. of the same serum, each receiving at the same time 0.25 c. c. of Scribner disease-producing blood. The remaining 3 pigs were left untreated to serve as controls. Unfortunately, as in Experiment XXII, we did not have a sufficient number of pigs to permit the injection of some with 0.25 c. c. of disease - producing blood alone and thus determine the protection afforded by the serum at the time of vaccination. For this reason we were forced to be content with the injection of larger pigs with a larger dose, 2 c. c., of disease-producing blood. The vaccinated and the unvaccinated pigs of this litter were left together with the sow after the vaccination; the larger pigs, 1821 and 1822, that were injected with disease-producing blood only, and their pen check, 1823, were placed in a pen to themselves.

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[a] For history of this immune see p. 21.

The death of the 2 hogs (1821 and 1822) from the diseased blood injection and the sickness and death of hog 1823 from association with these two show the virulence and the contagiousness of the disease produced by the blood used in the vaccination of the suckling pigs.

All of the vaccinated suckling pigs became slightly sick about twelve days after vaccination. The symptoms exhibited were droopiness and conjunctivitis, and slight diarrhea in some cases; this had all passed away after four or five days. None of the untreated pigs became sick. After the recovery of the vaccinated pigs the entire litter with the mother was placed in a pasture free from disease. They all thrived, and after being weaned were placed in the Scribner exposure pen on February 20, 1907, approximately four months after vaccination. As a result of this exposure all of the checks died and showed at autopsy the typical lesions of hog cholera. In marked contrast is the behavior of the vaccinated pigs, none of which became sick in the exposure pen.

The results of this experiment indicate (1) that suckling pigs may be vaccinated by using smaller doses of serum and disease-producing blood than is feasible in the case of larger hogs; (2) that the immunity conferred by the injection of these small doses of serum and disease-producing blood is quite durable, and (3) that the vaccinated pigs are not likely to transmit hog cholera to unprotected pigs that associate with them.

EXPERIMENT XXIV.—*Serum-simultaneous vaccination of suckling pigs, using serum from immune 1274.*

The pigs used in this experiment were 10 days old and weighed about 6 pounds each. On November 1, 1906, 3 of them were injected simultaneously with 3 c. c. of serum and 0.25 c. c. of disease-producing blood and 3 were left untreated. Two larger hogs (1867 and 1868) were given 2 c. c. of diseased blood alone, and an untreated hog was placed in the pen as a control on the contagiousness of the disease. Table 27 shows very clearly that this experiment was not a success, for 2 of the 3 vaccinated pigs died as a result of the treatment they received and 1 of the checks contracted disease from these and died, thus leaving only 1 treated pig with 2 checks for subsequent exposure. This exposure, which took place three months and twenty days after vaccination, caused the death of 1 of the checks, while the 2 other pigs remained well. Incidentally these results show that 0.25 c. c. of the disease-producing blood used in this experiment was sufficient to cause the death of suckling pigs.

EXPERIMENT XXV.—*Immunization of suckling pigs with serum alone from immune 1274.*

This experiment was designed to determine the protective power of the serum when used alone. A litter of 9 healthy pigs, 1 week old and weighing about 6 pounds each, was used. Five of these pigs were given 5 c. c. each of serum from hog 1274 subcutaneously on November 14, 1906, and the remaining 4 pigs were left untreated. As was to be expected, no sickness followed the injection of the serum, and the mother, with the entire litter of pigs, was placed in a lot supposed to be free from disease. They all remained well until some time during the month of January, when the checks were found to be sick. Pig 1988 was the first of these to die, but the other 3 checks did not live much longer. The vaccinated pigs all remained well. From the lesions found at the autopsy on the checks there seems to be no reason to doubt that these pigs died of hog cholera. We are unable to determine just when they were first exposed to infection, but it seems probable that this exposure took place about ten or twelve days prior to the death of the first pigs. This would place the date of exposure about January 10, approximately two months after the vaccination.

It is fair to assume, therefore, that the serum alone conferred upon the treated pigs immunity which lasted for two months at least.

TABLE 27.—*Third experiment with suckling pigs—first drawing of serum from hog 1274.*

No. of hog.	Weight.	Material injected.	Inoculation.		Exposure.		Autopsy.
			Date.	Result.	Date.	Result.	
	Pounds.						
1860		Sow—not treated					
1861	6	3 c. c. serum and 0.25 c. c. disease-producing blood of hog 1631.	Nov. 1, 1906	Sick Nov. 17; died Nov. 21, 1906.			Hemorrhagic lesions.
1862	6	do	do	Sick Nov. 26; died Nov. 30, 1906.			Do.
1863	6	do	do	Sick, but recovered	Feb. 20, 1907	Remained well	
1864	6	Not injected		Sick Dec. 1; died Dec. 11, 1906.			Ulcers.
1865	6	do		Remained well	Feb. 20, 1907	Remained well	
1866	6	do		do	do	Died Mar. 12, 1907	Do.
1867		2 c. c. disease-producing blood of hog 1631.	Nov. 1, 1906	Sick Nov. 7; died Nov. 11, 1906.			Hemorrhages and ulcers.
1868		do	do	Sick Nov. 7; killed Nov. 14, 1906.			Hemorrhages.
1869		Pen check with hogs 1867 and 1868		Sick Nov. 15; died Nov. 20, 1906.			Do.

The five treated pigs were given another exposure by being placed in the Scribner exposure pen on February 20, 1907. They did not thrive in this pen, but none of them contracted hog cholera.

Summary of results with suckling pigs.

In looking over the four experiments which have just been described and which were carried out with very young pigs it will be seen that serum from three different immunes was used, and this was given in varying doses. For this reason it is not possible by merely averaging the losses among vaccinated and unvaccinated pigs to determine the value of the serum for practical use, for it is probable that if we had used doses of 5 c. c. in all cases there would have been no deaths from vaccination, and in the light of the experiments with older pigs it also seems probable that this increased dose of serum would not have lessened the duration of immunity in the vaccinated pigs.

In spite of the facts just stated, it is at least interesting to consider all together the results of the experiments with suckling pigs. With 3 of the litters the serum-simultaneous method was used, while serum alone was used for vaccinating the fourth litter. In all, 10 suckling pigs were treated by the serum-simultaneous method, and all showed more or less marked symptoms of illness after vaccination, 3 of them finally dying of hog cholera. The remaining 7 recovered, and 6 of these were exposed to hog cholera in an infected pen from three and one-half to five months after vaccination; all remained well. In the same litters with these 10 vaccinated pigs there were 8 untreated pigs reserved as checks. Only 1 of these checks, all of which associated with the vaccinated pigs, con-

TABLE 28.—*Fourth experiment with suckling pigs—serum alone (first drawing) from hog 1274.*

No. of hog.	Weight.	Material injected.	Inoculation.		Exposure.		Autopsy.
			Date.	Result.	Date.	Result.	
	Pounds.						
1982		Sow—not treated		Remained well		Not exposed	
1983	6	5 c. c. 1274 serum alone	Nov. 14, 1906	do	Jan. 10, 1907	Remained well	
1984	6	do	do	do	do	do	
1985	6	do	do	do	do	do	
1986	6	do	do	do	do	do	
1987	6	do	do	do	do	do	
1988	6	Not injected		do	do	Died Jan. 22, 1907	Hemorrhagic lesions.
1989	6	do		do	do	Died Jan. 24, 1907	Hemorrhages and ulcers.
1990	6	do		do	do	Died Jan. 25, 1907	No autopsy.
1991	6	do		do	do	Died Jan. 29, 1907	Ulcers.

tracted hog cholera from them. Of the 7 remaining checks, 6 were exposed to hog cholera along with the 6 vaccinated pigs described above. Of the 6 checks, 5 died of hog cholera, thus showing a marked difference from the 6 vaccinated pigs, all of which remained well.

The remaining litter of pigs, it will be remembered, was treated with serum alone, 5 being given 5 c. c. of serum while 4 were reserved as checks and not treated in any way. Of these, all 4 of the checks died of hog cholera when exposed two months later, while the 5 vaccinated pigs all remained well.

The experiments with suckling pigs are not sufficiently extensive to warrant definite conclusions being drawn, and, especially in view of the success of the vaccination with serum alone, more experiments designed to test the duration of immunity resulting from such injections should be carried out, together with additional experiments with the serum-simultaneous method. The latter experiments should be carried out with somewhat larger doses of serum, and the immunity of the vaccinated pigs should first be tested at the end of six or eight months. We regard such experiments as being of great practical importance owing to the lessened cost resulting from the reduced dose of serum and the longer period of protection that might be secured by vaccinating suckling pigs.

CURATIVE VALUE OF HYPERIMMUNE SERUM.

In previous pages a large number of experiments dealing with immunization, through the use of serum alone, as well as through the combined action of serum and disease-producing blood, have been described, but in those experiments no attempt was made to determine the curative value of the immune serum.

Two experiments which were designed to throw some light upon this question have been carried out, but before proceeding to a description of these a few words should be said concerning the way in which the hogs used in these experiments were exposed to infection.

In vaccinating hogs by the serum-simultaneous method, it will be remembered, the method of introducing the infection consisted in the injection of the hogs subcutaneously with a fatal dose of disease-producing blood. The same end might have been attained by allowing the hogs which were to be vaccinated to associate with sick hogs, but owing to the uncertainty as to the exact time when infection would take place by mere association, and also because such a method would not be suitable for practical use, the blood-injection method of infection was used exclusively in the immunization work.

It will be understood, however, that in testing the curative power of a serum it is very desirable to carry out the experiments with animals under natural conditions as nearly as possible. For this reason, and also in order that we might compare results, one of the experiments to test the curative value of hyperimmune serum was carried out with hogs that had been exposed to infection by association simply, while in the other experiments hogs that had been infected through disease-producing blood injections were used.

In this connection it may be of interest, before considering the experiments designed to test the curative value of the serum, to note the results of a single experiment which was designed to test the effect of immediate exposure to hog cholera by association with sick animals upon hogs that had been injected with varying sized doses of immune serum.

EXPERIMENT XXVI.—*Immediate exposure of serum-treated hogs to disease by association.*

Six hogs were injected subcutaneously with serum from immune 1383; two received 5 c. c., two 10 c. c., and two 15 c. c. of the serum. Immediately after injection of the serum all were placed in the Scribner exposure pen. Two checks, not treated, were placed in the same pen several days later, as shown in Table 29.

TABLE 29.—*Experiment to test protective value of 1383 serum where the treated animals were given immediate exposure by association.*

No. of hog.	Weight.	Injected Oct. 3, 1906, with—	Exposure.		Autopsy.
			Date.	Result.	
	Pounds.				
1767....	50	5 c. c. serum..................	Oct. 3, 1906	Remained well.......	
1768....	50	.....do........................	.....do.......	Sickened Oct. 10; died Oct. 15, 1906.	Hemorrhages and ulcers.
1769....	40	10 c. c. serum.................	.....do.......	Remained well.......	
1770....	40	.....do........................	.....do.......	.....do...............	
1771....	45	15 c. c. serum.................	.....do.......	.....do...............	
1772....	50	.....do........................	.....do.......	.....do...............	
1773....	50	Unvaccinated check.........	Oct. 8, 1906	Sickened and died Nov. 4, 1906.	Hemorrhagic lesions.
1774....	50	.....do........................	.....do.......	Sickened and was killed Oct. 18, 1906.	Do.

With one exception (hog 1768, injected with 5 c. c. of serum) the hogs that received serum remained well, while both of the checks contracted hog cholera, one of them being killed to secure blood for other experiments. This experiment should be considered in connection with Experiment XXVIII, in which the same serum, instead of being injected simultaneously with the exposure to disease, was injected at varying intervals of time after exposure had taken place.

TABLE 30.—*Experiment to test curative value of 1383 serum.*

[Injected Sept. 29, 1906, with 2 c. c. of disease-producing blood of hog 1731.]

No. of hog.	Weight.	Injection with serum.		Interval between injection of disease-producing blood and injection of serum.	Result of injections.	Exposure.		Autopsy.
		Date.	Amount.			Date.	Result.	
	Pounds.							
1754	50	Oct. 1, 1906	15 c. c.	2 days	Remained well	Oct. 25, 1906	Remained well	
1755	50	do	do	do	do	do	do	
1756	50	Oct. 3, 1906	do	4 days	Slightly sick Oct. 5 to 16, 1906; recovered	do	do	
1757	50	do	do	do	do	do	do	
1758	50	Oct. 5, 1906	30 c. c.	6 days	Sickened Oct. 4; died Oct. 10, 1906			Hemorrhagic lesions.
1759	50	do	do	do	Sickened Oct. 4; died Oct. 12, 1906			Hemorrhages and ulcers.
1760	50	do	50 c. c.	do	Sickened Oct. 4; died Oct. 10, 1906			Hemorrhagic lesions.
1761	50	do	35 c. c.	do	do			Hemorrhages and ulcers.
1763	50	Oct. 7, 1906	50 c. c.	8 days	Sickened Oct. 4; died Oct. 10, 1906			Hemorrhagic lesions.
1764	50	do	do	do	do			Do.
1762	50		Not injected		Sickened from injection of diseased blood and died Oct. 4, 1906.			Do.
1765	50		do		Sickened from injection of diseased blood and died Oct. 10, 1906.			Do.
1766 *a*	50		do		Sickened Oct. 14; died Oct. 29, 1906			Hemorrhages and ulcers.

a Uninoculated pen check, exposed to hogs 1754 to 1765.

NOTE.—Hogs 1754 to 1761, inclusive, received first drawing of serum from hog 1383. Hogs 1763 and 1764 received second drawing of serum from hog 1383. All hogs in this experiment were kept together in one pen.

It is also interesting to compare these results with those of experiments in which the same serum was used in approximately the same doses, but in which the simultaneous exposure to disease was made by injecting disease-producing blood. (See Experiments V, VI, VII, and VIII.)

EXPERIMENT XXVII.—*Curative value of serum from hog 1383; exposure through blood injections.*

Twelve hogs weighing 50 pounds each were injected subcutaneously with 2 c. c. of blood from a sick hog on September 29, 1906. Of these 12 hogs, 2 were not given any serum, but were held as controls on the virulence of the diseased blood. One hog (1766) was not injected, but was placed in the pen with the others to test the contagiousness of the disease.

Two days after infection with disease-producing blood 2 of the infected hogs were injected with 15 c. c. of serum each; four days after infection 2 more hogs were given a similar dose of serum; six days after infection 4 more of the infected hogs were given serum, two being given 30 c. c. each, one 35 c. c., and one 50 c. c.; eight days after the disease-producing blood was administered the 2 remaining hogs of the 10 reserved for treatment were given 50 c. c. each of serum. The accompanying table (Table 30) illustrates very well the method of carrying out the experiment and the results obtained. The 2 hogs that were given the serum two days after injection remained perfectly well; those that were first given serum four days after infection became slightly sick, but recovered. The hogs that were given serum on the sixth and eighth days after infection were all sick when treated, but the course of the disease was apparently not affected by the treatment, although comparatively large doses of serum were used. The same serum, however, when administered simultaneously with disease-producing blood proved effective in quite small doses (5 c. c.—See Experiments V and VI). The 2 hogs (1762 and 1765) that were not treated with serum died promptly, as was to be expected, and the pen check also contracted disease and died. The 4 surviving hogs in this experiment were placed in the Syphax exposure pen a few days less than one month after the serum injection; all survived this exposure.

If conclusions may be drawn from this one experiment, we would infer that even very large doses of serum will not save hogs when it is injected more than four days after infection, but that prior to that time much smaller doses will suffice.

EXPERIMENT XXVIII.—*Curative value of serum from hog 1403; exposure by association.*

Twelve healthy hogs, weighing approximately 60 pounds each, were placed in the Scribner exposure pen on November 5, 1906. One day later 3 of these were removed from the exposure pen and 2 of the 3 were given 20 c. c. each of serum, the third hog being left untreated as a control. This procedure was repeated three times, 3 hogs being removed from the exposure pen on the second, the fourth, and the sixth days after exposure. In each instance 2 of the 3 hogs were injected subcutaneously with 20 c. c. of serum from hog 1403.

Table 31 shows that none of the hogs that were removed from the exposure pen within forty-eight hours after being placed there showed any signs of illness as a result of that exposure; even the controls which received no serum remained well. Of the 3 hogs that were taken out of the exposure pen four days after exposure all became sick, but the 2 that received serum recovered, while the control died. The results were almost precisely similar in the case of the 3 hogs that were removed from the exposure pen six days after having been placed

TABLE 31.—*Experiment to determine the curative value of serum of hog 1803 upon animals which had been exposed to virulent disease for varying lengths of time.*

No. of hog.	Weight.	Pen exposure.		Number of days in exposure pen.	Serum injected.			Pen exposure.		Autopsy.
		Date.	Result.		Date.	Amount.	Result.	Date.	Result.	
	Pounds.									
1870	70	Nov. 5 to 6, 1906	Remained well	1	Nov. 6, 1906	20 c. c.	Remained well	Dec. 4, 1906	Remained well	
1871	60	do	do	1	do	do	do	do	do	
1872	60	do	do	1		Not injected	do	do	Died Dec. 18, 1906.	Hemorrhagic lesions.
1873	60	Nov. 5 to 7, 1906	do	2	Nov. 7, 1906	20 c. c.	do	do	Remained well	
1874	60	do	do	2	do	do	do	Nov. 17, 1906	do	
1875	60	do	do	2		Not injected	do	Dec. 4, 1906	Died Dec. 18, 1906.	Hemorrhages and ulcers.
1876	60	Nov. 5 to 9, 1906	do	4	Nov. 9, 1906	20 c. c.	Slightly sick Nov. 16; recovered.			
1877	60	do	do	4	do	do	do			
1878	60	do	do	4		Not injected	Sick Nov. 15; died Nov. 24.			Do.
1879	60	Nov. 5 to 11, 1906	Slightly sick	6	Nov. 11, 1906	20 c. c.	Slightly sick; recovered.			
1880	60	do	Remained well	6	do	do	do			
1881	60	do	do	6		Not injected	Sick Nov. 13; died Nov. 24, 1906.			Hemorrhagic lesions.

there, for in this case also the 2 serum-treated hogs recovered after having been somewhat sick, while the untreated control died of hog cholera.

In summing up the results of this experiment, the behavior of hogs 1870 to 1875, inclusive, when later exposed to infection, must be taken into consideration, for the deaths of control hogs 1872 and 1875 as a result of this second exposure shows that they were all along susceptible to the disease. This points strongly to the likelihood that none of the first 6 animals in this experiment became infected from the first exposure of one and two days, respectively, in the exposure pen, and the immune serum can not, therefore, be considered as having exerted any curative influence in these cases, although its immunizing action is well shown by the exposure of December 4, 1906, just referred to.

The hogs that were treated with serum four days and six days, respectively, after being placed in the exposure pen can not be regarded as having become infected at once after being placed in the exposure pen, for, as shown by the behavior of the controls in the lots that were removed on the first and second days, infection probably did not take place in any of the hogs during the first forty-eight hours in the exposure pen. On the other hand, it is quite evident from the behavior of hogs 1876, 1877, and 1878 that infection did take place some time prior to the end of the fourth day in the exposure pen. While it is impossible, as already stated, to fix the time of infection with exactness, we know that it took place on the third or fourth day. It is plain, therefore, that the serum in doses of 20 c. c. saved the life of hogs that had been infected from two to four days previously.

DISCUSSION OF CURATIVE ACTION OF IMMUNE SERUM.

Earlier experiments have shown that the serum from hyperimmunized immunes, when given in sufficient dose, may be expected to protect nonimmune hogs from a simultaneous infection with hog cholera, and the two experiments just described show that this serum may also be expected to prevent the death of hogs when it is administered in moderate doses within four days after infection actually takes place. Later than this it is probable that the serum in virulent attacks of hog cholera will do little good, even though comparatively large doses are given. For this reason it seems possible that serum from immunes prepared in the manner described in this paper may not prove suitable for general use as a curative agent for hog cholera, although in cases where the disease is recognized soon after its appearance in a herd the serum would probably save many hogs that had been exposed only a few days. In stating that the serum should be administered within four days after infection to insure success, we wish to make it plain that we refer to the date of actual infection and not to the time of first exposure, for, as is shown by Experiment XXVIII, several days may elapse before infection takes place after exposure to disease by association. (See records of hogs 1872 and 1875, Experiment XXVIII.)

DURATION OF PROTECTIVE POWER IN BLOOD OF IMMUNES, AND KEEPING QUALITY OF HYPERIMMUNE SERUM.

The original plan of our experiments included the testing of serum drawn from the immunes at different periods of time after the last injection of disease-producing blood, and we were able in some instances to test the second and third drawings of immune serum, but as these later drawings of serum were apparently quite as potent as the first drawing, the question of the duration of protective power in the blood of the immune had not been decided by the experiments already described. For the purpose of testing this matter still further a special experiment was carried out with a drawing of serum from immune 1234. This hog furnished part of the serum used in the 1905 experiments. (See p. 11.)

TABLE 32.—*Potency of serum from hyperimmunized immune 1234, seven and one-half months after last injection with disease-producing blood.*

[Experiment with serum from hog 1234 ("slow" immune—1905).]

No. of hog.	Weight.	Material injected.	Inoculation.		Pasture exposure.		Pen exposure.		Autopsy.
			Date.	Result.	Date.	Result.	Date.	Result.	
	Pounds.								
1657	45	10 c. c. serum and 2 c. c. disease-producing blood of hogs 1568 and 1614.	Sept. 3, 1906	Sick Sept. 11 to 16, 1906; recovered.	Oct. 15, 1906	Remained well	Dec. 22, 1906	Remained well	
1658	45	do	do	Sick Sept. 12 to 16, 1906; recovered.	do	do	do	do	
1659	90	20 c. c. serum and 2 c. c. disease-producing blood of hogs 1568 and 1614.	do	Sick Sept. 11 to 23, 1906; recovered.	do	do	do	do	
1660	45	do	do	do	do	do	do	do	
1661	55	2 c. c. disease-producing blood of hogs 1568 and 1614.	do	Sickened Sept. 9; died Sept. 14, 1906.					Hemorrhages and ulcers.
1662	45	do	do	Sickened Sept. 9; died Sept. 17, 1906.					Hemorrhagic lesions.
1663	45	do	do	Sickened Sept. 9; died Oct. 6, 1906.					Hemorrhages and ulcers.
1664	40	Pen check with hogs 1661, 1662, and 1663.		Sickened Sept. 19; killed Sept. 26, 1906.					Do.

EXPERIMENT XXIX.—*Potency of serum drawn seven and one-half months after last treatment of immune.*

This experiment practically repeats the test of serum from immune 1234 that was carried out in 1905. Two hogs were injected with 10 c. c. of serum and 2 c. c. of disease-producing blood each, and 2 with 20 c. c. of serum plus the usual dose of disease-producing blood; at the same time 3 hogs were injected with 2 c. c. each of disease-producing blood alone, and 1 healthy hog was placed in the pen with these in order to make sure of the infectiousness of the disease.

Table 32 shows the manner of carrying out this experiment as well as the results obtained. The significance of the experiment may perhaps be best appreciated by a comparison of the action of serum from the same hog drawn nearly a year before, shortly after an injection of disease-producing blood. The action of blood from nonhyperimmunized immunes, as shown in Experiments XX and XXI, should also be kept in mind.

Table 32 shows that all of the vaccinated hogs became sick as a result of the treatment, but they all recovered. The 3 hogs (1661, 1662, and 1663) that received the same dose of the same disease-producing blood alone likewise became sick and all died, and they communicated the disease to their pen check.

The vaccinated hogs were exposed to hog cholera during the pasture outbreak about six weeks after vaccination. They all remained well and when placed in the Scribner exposure pen three months and nineteen days after vaccination were still completely immune to the disease.

Inasmuch as 10 c. c. and 20 c. c. of serum drawn from immune 1234 in 1905 gave complete protection from a fatal dose of disease-producing blood, and as the last drawing, made seven and one-half months after the last treatment with disease-producing blood, gave only partial protection (the serum in this case prevented death, but did not prevent illness), we may conclude that the protective power of the blood of immune 1234 had diminished somewhat seven and one-half months after the last disease-producing blood injection. But although the potency was diminished, it was still present in a marked degree, and although, owing to the limited number of tests that have been made, we can not be absolutely certain, it is at least reasonable to believe that this power was due to the previous injections of disease-producing blood and not to a natural protective power existing normally in the blood of the immune. (See experiments with blood from nonhyperimmunized immunes, p. 71.) This question is one of practical importance, and further experiments along this line will be carried out.

EXPERIMENT XXX.—*The keeping quality of immune serum.*

A quantity of hyperimmune serum prepared in 1905 remained unused in the experiments of that year, and as it was very desirable to know how long the serum, prepared with carbolic acid, would retain its potency, we have utilized some of this 1905 serum in experiments designed to test this point.

The serum used was from 1905 immunes Q No. 2 and 1234, and was drawn from these hogs on December 1, 1905, and November 21, 1905, respectively. Immediately after being drawn these sera were mixed with a 5 per cent solution of carbolic acid in such proportion that the serum contained 0.5 per cent carbolic acid. After the addition of this preservative the serum was placed in sterilized bottles and kept in a cool place until June 6, 1906, when it was used in the following experiment.

Two hogs, W 1925 and W 1926, were injected subcutaneously with 5 c. c. of Scribner disease-producing blood, and at the same time hog W 1925 was given 20 c. c. and hog W 1926 was given 17 c. c. of hyperimmune serum from hog 1234. Hogs W 1928 and W 1929 were given 5 c. c. each of the same disease-producing blood, but

TABLE 33.—*Experiment to test keeping quality of immune sera.*

No. of Hog.	Material injected.	Inoculation.		Pen exposure—Scribner.		Autopsy.
		Date.	Result.	Date.	Result.	
W 1925	20 c.c. serum of 1234 and 5 c.c. disease-producing blood of hog 1910.	June 7, 1906	Remained well	July 27, 1906	Slightly sick Aug. 6 to 8, 1906; recovered.	
W 1926	17 c. c. serum of 1234 and 5 c. c. disease-producing blood of hog 1910.	do	do	do	Remained well	
W 1927	Pen check with hogs 1925 and 1926		do	do	Sickened Aug. 6; died Aug. 12, 1906.	Hemorrhagic lesions.
W 1928	20 c. c. serum of Q No. 2 and 5 c. c. disease-producing blood of hog 1910.	June 7, 1906	do	do	Remained well	
W 1929	do	do	do	do	do	
W 1930	Pen check with hogs 1928 and 1929		do	do	Sickened Aug. 4; died Aug. 11, 1906.	Do.
W 1931	5 c. c. disease-producing blood of hog 1910.	June 7, 1906	Sickened June 26; died July 9, 1906.			Hemorrhages and ulcers.
W 1932	do	do	Sickened June 26; died July 19, 1906.			Ulceration of cecum.

NOTE.—This experiment was carried out at Bethesda, Md., with sera from immune hogs 1234 and Q No. 2; these hogs were immunized at Ames, Iowa, in the fall of 1905, hog 1234 by the slow method and hog Q No. 2 by the quick method. The sera used in the above experiment were prepared from second drawings of blood.

received 20 c. c. each of hyperimmune serum from immune Q No. 2. An untreated hog was placed in each of the two pens with the vaccinated hogs. As controls, 2 hogs (W 1931 and W 1932) were each given 5 c. c. of the same disease-producing blood as was used for injecting the 4 serum-treated hogs. These 2 hogs were placed in a separate pen.

As may be seen from Table 33, none of the 4 hogs that received the simultaneous injections of serum and disease-producing blood showed any symptoms of illness after injection, while both of the hogs that were given the disease-producing blood alone sickened and died of hog cholera. The 4 vaccinated hogs, with their 2 pen checks, were exposed to hog cholera about seven weeks after vaccination. As a result of this exposure, both check animals died of hog cholera, while 1 of the vaccinated hogs became slightly sick, but soon recovered. The 3 other vaccinated hogs did not show any signs of illness.

This experiment shows that hyperimmune serum preserved with carbolic acid may retain its potency for at least six months.

GENERAL SUMMARY OF RESULTS.

In the experiments of 1905 and 1906, 13 immune hogs (including hog 1401) were used for the production of serum, and all of these, with one exception (immune Q No. 1, 1905), after hyperimmunization have furnished serum that in doses of 15 c. c. or more gave protection from a simultaneous injection of disease-producing blood. When smaller doses of serum were given, differences in the potency of the various sera could be observed. The doses of immune serum given with disease-producing blood varied from 2½ to 20 c. c., and, as was to be expected, some of the hogs that received the smaller doses were not sufficiently protected. In summarizing the results of these experiments, therefore, the percentage of loss which resulted from vaccination is not to be regarded as representing what would occur in the practical application of the method, for, as already stated, when a sufficient dose of serum is used no deaths are caused by the immunizing treatment. Even though, for the reasons just stated, the average results of our experiments are not to be considered as representing what should be obtained in practice, a summary of these results is not without interest as showing in a general way the behavior of serum-treated hogs as compared with unprotected hogs when both are exposed to disease through injections of disease-producing blood.

In all, 168 hogs were given a simultaneous injection of serum and disease-producing blood, the dose of serum varying from 2½ c. c. to 20 c. c. Of these, 35, or 21 per cent, showed visible symptoms of illness after injection, and 15, or approximately 9 per cent of the total number, died. As a contrast to this we find that 54 hogs were injected with the same dose of the same disease-producing blood alone. Of these, 54, or 100 per cent, became sick, and 50, or 92.5 per cent, died of hog cholera. These figures, we believe, show beyond doubt that by hyperimmunizing immunes in the manner described in this paper a highly potent serum may be secured. We are confident also, as a result of the experiments we have described, that had we used the larger doses of serum in all cases or else reduced the dose of disease-producing blood the percentage of deaths following vaccination would have been so small as to be without practical significance.

TRANSMISSION OF DISEASE BY HOGS TREATED BY SERUM-SIMULTANEOUS METHOD.

To test the possibility of disease being conveyed to normal hogs by hogs that had been vaccinated, 58 shoats were placed in the pens with the vaccinated hogs. Of these pen checks none became sick unless some of the vaccinated hogs with which they associated became severely ill; indeed in a number of instances the pen checks remained well, even though they associated with vaccinated hogs exhibiting undoubted symptoms of hog cholera. From this it appears that the immune serum not only possesses the power to protect hogs from a simultaneous injection of disease-producing blood, but that even in cases where too little serum is given it yet has a marked tendency to lessen the infectiousness of the disease. Of the 58 pen checks exposed to vaccinated hogs, 6 contracted hog cholera and 5 died.

As a control experiment, 19 shoats were placed in the pens with the hogs that were injected with disease-producing blood alone. Of these, all became sick, 17 died, 1 was killed to secure blood for other experiments, and 1 recovered. In other words, of the pen checks exposed to hogs injected with disease-producing blood alone, 94 per cent died, whereas only 8 per cent of the checks exposed to vaccinated hogs succumbed.

IMMUNITY IN HOGS AFTER SERUM-SIMULTANEOUS VACCINATION.

In describing the individual experiments attention has been called to the accidental exposure to hog cholera of those vaccinated hogs that were being reserved for a late exposure in order to test the duration of the immunity conferred by the serum-simultaneous and the serum-alone methods. The pasture in which this accidental outbreak of disease occurred contained a large number of hogs which had been treated at different times, and as a consequence this exposure took place only a few weeks after vaccination in the case of some of the hogs, while in the case of others the interval between vaccination and exposure was as great as three months. Aside from the hogs that were accidentally exposed in this way, a considerable number were placed in the exposure pen within three weeks after vaccination, the object being to compare the immunity at this time with that exhibited by others treated in the same way but exposed very much later. For the reasons given, this comparison could not be made in all cases, and all results of exposure to hog cholera are therefore considered together in this summary, it being understood that exposure took place from three weeks to three months after vaccination.

Of the hogs treated by the serum-simultaneous method, 136 were exposed to hog cholera, and 4, or nearly 3 per cent, died as a result, while of 68 unvaccinated hogs exposed under the same conditions, 56, or approximately 82 per cent, died.

In regard to the 4 vaccinated hogs that are stated to have died from exposure after vaccination, it should be noted that there is room for considerable doubt as to the cause of death. In only one of these hogs (1780) were typical lesions of hog cholera found at autopsy; and as this hog remained unthrifty after vaccination, and as its mate (1781) treated in the same manner died from vaccination, it is not unlikely that the intestinal lesions found at the autopsy of hog 1780 resulted from vaccination and not from exposure. Neither of the other three hogs exhibited lesions of hog cholera at autopsy, and two of them (1552 and 1556) passed through exposure in the pasture and only succumbed when placed in the exposure pen. The conditions in this exposure pen were not conducive to thriftiness, for no attempt was made to disinfect or clean the pen, as this might have defeated its object, which was to furnish a certain and severe exposure to hog cholera. Before leaving this subject, we wish to state our conviction that as small as was the loss among vaccinated hogs exposed to hog cholera, this would have been even less had the exposure taken place under the conditions usually met with in practice.

IMMUNITY IN HOGS TREATED WITH SERUM ALONE.

In all, 58 hogs were treated with serum alone in the experiments of 1906. None of these showed any ill effects from the treatment, and 49 were subsequently exposed to hog cholera. Of these, 23, or 47 per cent, survived exposure, whereas of 68 untreated hogs which served as controls only 18 per cent survived. It is thus evident that the protection afforded by the hyperimmune serum when given alone, while it did not equal that afforded by the serum-simultaneous method, was nevertheless sufficient to protect nearly 50 per cent of the treated animals against subsequent exposure.

As regards the duration of the protection afforded by the serum when given alone, we find that of 49 animals treated with serum alone, 26 were exposed within three weeks after receiving the serum, and 23 were exposed after one to three and one-half months. Of the first lot, exposed within three weeks, 9, or 34.6 per cent, died as a result of the exposure, while of the 23 exposed after one to three and one-half months, 17, or 73 per cent, succumbed. From these results it would seem that the protection afforded by the serum when administered alone is not as lasting as when administered in combination with diseased blood.

CURATIVE VALUE OF HYPERIMMUNE SERUM.

The exact methods of carrying out the experiments has been described elsewhere. Twelve hogs that were certainly infected with hog cholera were treated with serum after the elapse of different lengths of time, and the results showed that doses of 15 or 20 c. c. were sufficient to save the life of the treated hogs, provided the serum was given within four days after the date of infection. If given later than this, even much larger doses (35 to 50 c. c.) were not sufficient to save the infected hogs from the severe exposure to which they were subjected.

RESULTS WITH SERUM FROM IMMUNES TREATED BY DIFFERENT METHODS WITH DIFFERENT DISEASE-PRODUCING BLOODS.

In the previous summaries simply the general results have been considered, without reference to any differences that may have been found in the action of serum prepared by the different methods or by the use of different strains of disease-producing blood, and also without regard to differences in the immunes themselves. In discussing these features we wish to call attention again to the fact that the figures given are not to be taken as representing what may be expected in actual practice, for it is probable that all of the serum would have given better results if the doses had been somewhat larger in certain cases.

COMPARISON OF THE QUICK AND SLOW METHODS OF PRODUCING HYPERIMMUNE SERUM.

The comparative potency of the sera prepared by the quick and slow methods may no doubt be best shown by comparing the results obtained by injecting nonimmune hogs simultaneously with serum and a fatal dose of disease-producing blood. In the experiments of 1905 and 1906, 86 hogs[a] were treated in this way with serum prepared by the quick method. Of these 86 hogs, 7, or approximately 8 per cent, died from the injection. There were treated with serum prepared by the slow method 82 hogs, all of which were injected at the same time with disease-producing blood. Of these, nearly 10 per cent died as a result of the injection. The slight difference in favor of the quick method we are inclined to attribute to other causes than to the method used for producing the serum, and it seems probable that one method will be found as suitable as the other for producing a potent serum, though of course in either case the potency might be heightened by increasing the dose of disease-producing blood given the immune. The potency of the serum secured being equal, the quick method would probably be found more desirable for practical use.

THE COMPARATIVE POTENCY OF SERA SECURED BY HYPERIMMUNIZATION WITH THE SCRIBNER AND SYPHAX STRAINS OF DISEASE.

Serum from 8 hogs was used, 4 having been hyperimmunized with Scribner disease-producing blood, and 4 with Syphax blood. In all, 74 hogs were treated with serum from the Scribner immunes at the same time that they were injected with disease-producing blood; as a result, 4, or approximately 5½ per cent, died. In the case of the serum from the Syphax immunes, 72 hogs were given disease-producing blood simultaneously with serum, and, as a result, 8, or 11 per cent, died. The apparent lower potency of the Syphax hyperimmune serum is caused by the distinctly weaker power of the serum from 1 hog (1310), a dose of 10 c. c. of this serum being too small to protect nonimmunes, although larger doses were entirely satisfactory. Inasmuch as the average potency of the serum from the other 3 immunes hyperimmunized with the Syphax blood was quite as great as that of those treated with the Scribner blood, we are inclined to believe that the lower potency of serum from hog 1310 was due to some peculiarity of this hog and not to a lower hyperimmunizing power of the Syphax blood.

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[a] This includes the hogs treated with serum from immune 1401.

COMPARATIVE POTENCY OF SERA FROM HOGS POSSESSING NATURAL IMMUNITY AND FROM THOSE POSSESSING ACQUIRED IMMUNITY.

Attention has already been directed to the difficulty experienced in deciding whether a particular animal should be classed as one possessing acquired immunity or natural immunity. In fact the whole question seems to be simply one of degree of resisting power on the part of the hog. In any outbreak of hog cholera it is probable that at least a few hogs will survive. Some of these may have been markedly sick and have recovered only after a long siege of the disease, while others may have been only slightly indisposed, and still others may not have exhibited visible symptoms of disease. It seems hardly correct to speak thereafter of one of these hogs as a natural immune, and to regard another as having acquired immunity through the attack of disease. We are rather inclined, in the light of our present knowledge of the disease, to regard all hogs as being naturally susceptible but varying greatly in the degree of resisting power which they possess. If this assumption be correct, it would be expected that a protective serum might be obtained by the hyperimmunization of any immune hog, the differences in the serum from different hogs being simply in degree of potency and depending probably upon the intensity of the reaction produced by the injection of diseased blood.

In actual practice we have been able to secure but one immune that had actually been sick of hog cholera that was vigorous and suitable for hyperimmunization. The serum from this immune (1392), as the records show, is not more potent than that obtained by similar methods of hyperimmunization from other hogs that had never shown visible symptoms of illness when exposed to hog cholera. In fact the sera from the different immunes, with the exception of hogs Q No. 2 and No. 1310, were quite uniform in potency. The lesser potency of the sera from the two hogs just mentioned can not be explained upon the ground of natural immunity, but probably was caused by some individual peculiarity which we do not understand.

The remaining experiments, not mentioned in this general summary, have already been discussed at some length and it seems unnecessary to refer to them further at this time. Before closing this discussion, however, we wish to suggest to anyone who may have occasion to repeat these experiments that it is essential to make sure that the outbreak from which blood is secured for hyperimmunization exhibits all of the characteristics of hog cholera[a] and likewise that the blood used in conjunction with the serum for serum-simultaneous vaccination is taken from a hog suffering from undoubted hog cholera. In addition, more than one hog should be hyperimmunized in order that individual peculiarity on the part of one hog may not lead to erroneous conclusions. As the methods herein described involve the use of a disease-producing virus we believe that only those trained in bacteriological methods should attempt to use them, and in all cases before the serum is employed in a practical way the amount required to give protection from a fatal dose of disease-producing blood should be determined experimentally.

CONCLUSIONS.

(1) When hogs immune from hog cholera are injected with suitable amounts of virulent blood taken from hogs sick of hog cholera the blood serum of the immunes acquires the power to protect nonimmune hogs from an otherwise fatal dose of disease-producing blood administered simultaneously with the serum.

(2) Immunes which have never exhibited symptoms of disease after exposure to hog cholera (natural immunity) may furnish equally as potent serum as those which have recovered from an attack of the disease (acquired immunity).

(3) Hyperimmunization may be accomplished equally as well by the administration of one large dose of disease-producing blood as by repeated injections of smaller doses.

(4) Hyperimmunization may be accomplished with blood from any virulent strain of hog cholera.

(5) Hyperimmunized hogs probably retain for several months the power to furnish a potent serum.

(6) Serum from properly hyperimmunized hogs in doses of 20 c. c. should protect nonimmunes weighing from 25 to 50 pounds from a fatal dose of disease-producing blood administered simultaneously.

(7) Immunity in hogs treated by the serum-simultaneous method lasts at least three and one-half months and probably longer.

(8) In serum-simultaneous vaccination it is not necessary to produce illness in the vaccinated hog in order to secure an immunity lasting for at least three months.

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[a] See Bulletin 72, Bureau of Animal Industry, p. 12.

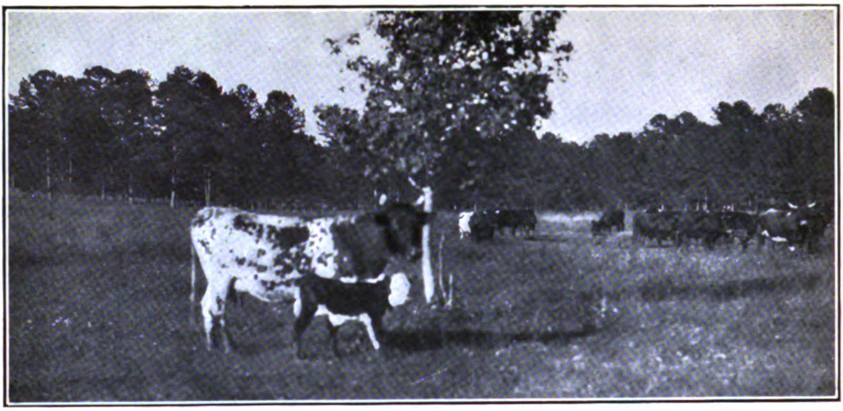

FIG. 1.—NATIVE ALABAMA COW WITH CALF BY PUREBRED HEREFORD BULL.

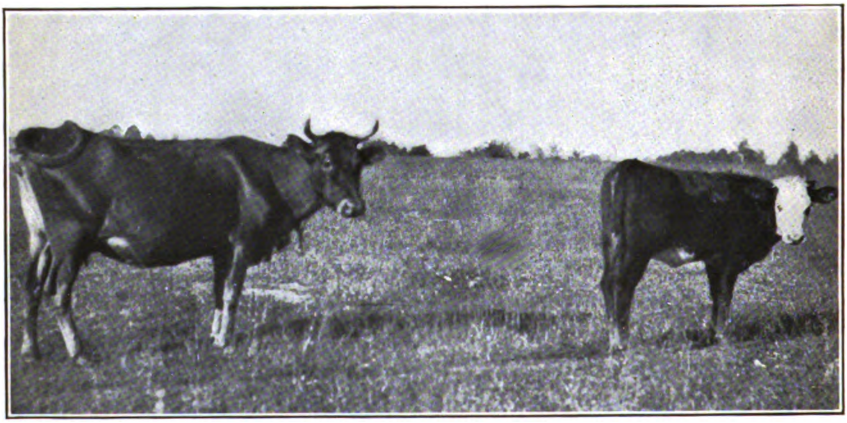

FIG. 2.—NATIVE ALABAMA COW WITH CALF BY PUREBRED HEREFORD BULL.

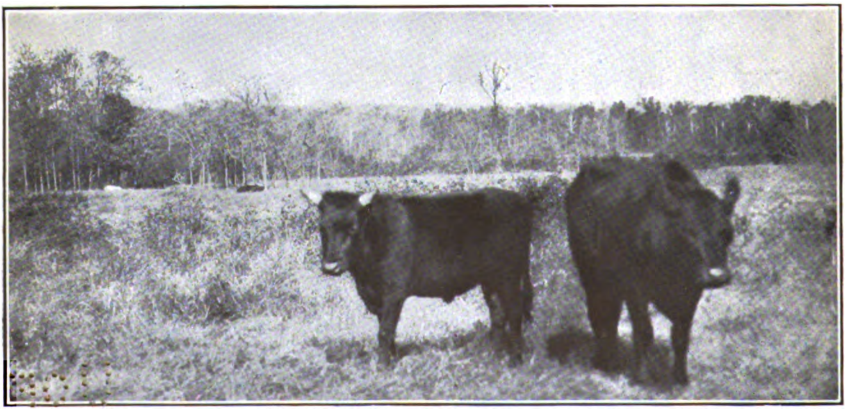

FIG. 3.—RELATIVE SIZE OF 3-YEAR-OLD SCRUB STEER AND PUREBRED ANGUS COW OF SAME AGE.

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A. D. MELVIN, CHIEF OF BUREAU.

EXPERIMENTS IN BEEF PRODUCTION IN ALABAMA.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., December 23, 1907.

Sir: I have the honor to transmit herewith for publication as a bulletin of this Bureau a manuscript entitled "Experiments in Beef Production in Alabama," by Director J. F. Duggar, of the Alabama Agricultural Experiment Station, and W. F. Ward, scientific assistant. The work was done before Director Duggar turned over this work to Prof. Dan T. Gray, who is now in charge.

The bulletin is the result of three years' cooperation with the Alabama Experiment Station in steer feeding, and covers in a comprehensive manner tests of different feeding methods in use by Alabama stockmen or considered worthy of trial in that section. This will be the first bulletin published by the Bureau giving results obtained as a direct result of the appropriation for experiments in animal breeding and feeding in cooperation with State agricultural experiment stations.

Respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The investigations reported by Director Duggar and Mr. Ward in this bulletin, although complete in themselves, were planned to be preliminary to a systematic study of the economy of beef production under southern conditions, especially in sections east of the Mississippi River. As a basis for work it was important to know thoroughly the value of southern feeds in steer feeding.

The greatest agricultural necessity of the South to-day is live stock. There are several reasons for this, some of which are to supply local demands, to utilize the southern feedstuffs to best advantage, and to restore fertility to worn-out fields. To meet these demands, a study must be made of every phase of animal husbandry—the value of southern feeds, the value of purebred sires to improve the native stock, economy of production, the relation of southern markets to the development of the stock-raising industry, and the influence of soil and climatic conditions.

The results set forth in this bulletin add much valuable information to that in bulletins already published by southern experiment stations, especially as showing the relative values of various feeds and rations. The value of purebred sires has been generally acknowledged, but it is not yet put into practice to any great extent. Emphasis must be placed not only on the inferiority of native stock, but on the rapid improvement that can be made by using purebred sires. Two instances may be seen in Plate I of this bulletin.

As to economy of production, the results of these investigations show that much is to be learned, and as to market conditions there is a great deal more to be learned. Soil and climatic conditions have received very little attention and will repay close study.

With the progress of the campaign for the extermination of the cattle tick, these problems become still more pressing.

George M. Rommel,
Animal Husbandman, Bureau of Animal Industry.

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EXPERIMENTS IN BEEF PRODUCTION IN ALABAMA.

INTRODUCTORY.

Within the past decade there has been a decided increase in the interest manifested in the growing of beef cattle in the Gulf States east of the Mississippi River. This has been largely due to a decrease in the amount of labor available on farms and to the belief that the losses due to the presence in this region of the cattle tick are in a fair way of being eliminated, either by the artificial immunization of valuable breeding animals brought from higher latitudes or by the eradication of the tick. The outlook regarding the last-named solution of the difficulty is very encouraging, in view of the success attending the work now being done by the Bureau of Animal Industry with the cooperation of the State authorities and the cattle owners.

Numbers of bulls of the beef breeds have been brought into the South during the last decade; consequently the number of grade beef cattle has rapidly increased. Assuming that a grade animal of the beef breeds can be raised at a profit when making its living on pasturage on low-priced lands, there still remains the open question, so far as this region is concerned, whether there is most profit in marketing this animal directly from the pasture or in feeding it for one winter just before shipping so as to sell it at a considerably higher price per pound. Of course a variable answer to this question will be had, dependent (1) upon the difference in price paid for southern cattle from the pasture and from the feed lot; (2) upon the prices, always fluctuating, of southern feedstuffs; (3) upon the quality of the animals fed, and (4) upon a number of other conditions.

It was to throw light upon some of these questions that the following experiments were undertaken jointly by the Alabama Agricultural Experiment Station and the Bureau of Animal Industry of the United States Department of Agriculture.

Most of the feeding of cattle in Alabama for fattening purposes is done in the vicinity of the cotton-seed oil mills, and almost exclusively the ration consists of cotton-seed meal and cotton-seed hulls. The high prices of cotton-seed feed products prevailing during the past few years have tended to prevent the extension of winter feeding operations. Those who have been so situated that they could obtain cotton-seed meal and cotton-seed hulls at a low price have been able to continue feeding. Usually cotton-seed meal is cheaper in the immediate vicinity of the cotton-oil mills, and when purchased under a contract made before the beginning of the crushing season. A favorite method of securing low prices for cotton-seed meal and for cotton-seed hulls by those who have the disposal of large amounts of cotton seed consists in the exchange by the farmer of cotton seed for the manufactured feed products of the oil mills.

The experimental work here described was at a disadvantage in all these respects, so that the feedstuffs cost more than would be the case with more extensive feeders who are more favorably circumstanced. Nevertheless, in spite of high prices of feed the experiments were entered upon with the expectation that they would afford some data as to the relative values of the principal southern feedstuffs, even though they should not afford profitable results while the prices of feed should continue high.

The principal inducement for farmers to feed cattle on purchased feeds, chiefly cotton-seed meal and cotton-seed hulls, is the great value of the manure produced from this rich ration. For the farmer who habitually purchases cotton-seed meal for use as a fertilizer it is sound policy first to pass this feed through cattle, after which its fertilizing value, if no losses occur, should be more than four-fifths of its original fertilizing value. Unfortunately fermentation, leaching, and mechanical losses of the manure and the cost of handling this bulky article must be taken into account as deductions from the theoretical value of the manure. Even after this is done such manure is a most profitable fertilizer, and these losses are merely noted here as a means of cautioning farmers to reduce them to the lowest possible limit when feeding is done chiefly as a means of obtaining a supply of manure. Doubtless if, in the following experiments, we had been able to determine the exact amount and value of the manure produced there would have been a profit from feeding operations which, as here figured, independent of the manure, were often unprofitable.

OBJECTS OF THE EXPERIMENTS.

In planning these experiments two main objects were in view. These were to throw additional light on the questions (1) whether farm-grown forage can be substituted profitably for cotton-seed hulls, the usual roughage, and (2) to determine the relative values of the most common southern concentrated feedstuffs—cotton seed, cotton-seed meal, and corn. The experiments were conducted with a total of 150 steers; 50 steers were fed for each of three winters under as nearly the same conditions as possible. The steers were 2-year-old grades of the beef and dual-purpose breeds, except that one pen each year consisted of typical scrubs. The animals were divided into 10 lots of 5 steers each, in such a way that the results obtained would permit of the following comparisons:

1. Sorghum hay or fodder versus cotton-seed hulls.
2. Shredded corn stover versus cotton-seed hulls.
3. Sorghum hay or fodder versus shredded corn stover.
4. Corn-and-cob meal versus cotton seed as the principal concentrate.
5. Cotton-seed meal versus corn as an appetizer in a cotton-seed ration.
6. The effects of substituting corn-and-cob meal for a part of the cotton-seed meal.
7. The value, if any, of shelter in fattening southern steers.
8. A comparison of scrubs with grades of the beef breeds or dual-purpose breeds.

DETAILS OF THE EXPERIMENTS.

THE STEERS USED.

The grade steers used were in most cases 2-year-old half bloods. They were out of native cows from bulls of the Angus, Shorthorn, Red Polled, Hereford, and Devon breeds, and were obtained in Wilcox and Sumter counties in the central prairie region of Alabama. They were not as uniform as desirable, because of the fact that they were obtained from different men, as no one man had very many of the size and quality desired.

The steers used in the first experiment (1904–5) were smaller, thinner, and poorer in quality than those in the two following years. The steers were in quality from "common" to "good," the majority being classed as "medium feeders."

The scrubs used were about the average quality of scrubs and were typical specimens of their kind. They were 3 and 4 year olds. About half of them showed traces of Jersey blood, as do a considerable proportion of the scrub cattle of Alabama. They were thinner in flesh than the grades in the first experiment, and this undoubtedly accounts for their larger gains the first year.

The grade steers were valued at 3 cents a pound when put on feed. The scrub steers cost 2½ cents a pound.

SHELTER, FEED LOTS, AND WATER SUPPLY.

The feed lots were 16 by 90 feet, the ground sloping away from the shed. These lots had a good slope, but still became very muddy in wet weather. The lot without shelter was at times several inches deep in mud, so that the steers had no dry place to lie down. None of the lots were bedded, though the sheds were. The feed troughs were under the sheds. The water troughs were near the feed troughs and under the shed, the water being supplied from a well. The troughs had float valves, so that a fresh supply of water was kept in them at all times.

WEIGHING, ETC.

The steers were numbered by means of tags in the ears. At the beginning of the preliminary period the steers were weighed and divided as equally as possible with a view to getting the pens uniform in quality and weight. At the beginning and close of the feeding experiment proper the steers were weighed three days in succession to get an average weight. The weighing was begun at 10.30 a. m., the steers having had access to both feed and water. Each steer was weighed at the end of every week.

METHOD OF FEEDING.

The feed was weighed out twice daily and fed at 7 a. m. and 5.30 p. m. The roughage and concentrate were fed at the same time. The steers were fed all the roughage they would eat up clean. They were salted once a week, two days after weighing. They were started on a small grain ration, and this was gradually increased until they were eating a full grain ration. A close watch was kept on them to see that there was no scouring, as this is common in feeding cotton seed or cotton-seed meal in large quantities. There was little scouring, it being confined chiefly to the pens getting cotton seed. There was a greater tendency to scour as warm weather came on, so at times the grain ration had to be cut down slightly. The pens getting cotton-seed hulls had the concentrate mixed with the hulls in the feed troughs. Those getting surghum had the grain mixed with the cut sorghum in the same way as the pens getting cotton-seed hulls. The cowpea hay and the corn stover were fed in racks just over the feed troughs, so that any waste would drop into the troughs.

Since the laxative effects of cotton seed restricted the amounts of concentrate fed to pens 8 and 9, it was necessary to reduce the corn ration of pen 10 far below the amount of corn usually fed, so that the amount of concentrates fed to these three pens would be the same. The feeding period occupied 84 days each year.

CHARACTER AND COST OF FEEDS USED.

The cotton-seed meal fed was of average quality, as were the cotton seed, corn, and cotton-seed hulls. The husked corn was coarsely ground, and 70 pounds was found to be equivalent to 1 bushel of shelled corn. The corn stover was inferior, being coarse and very dry.

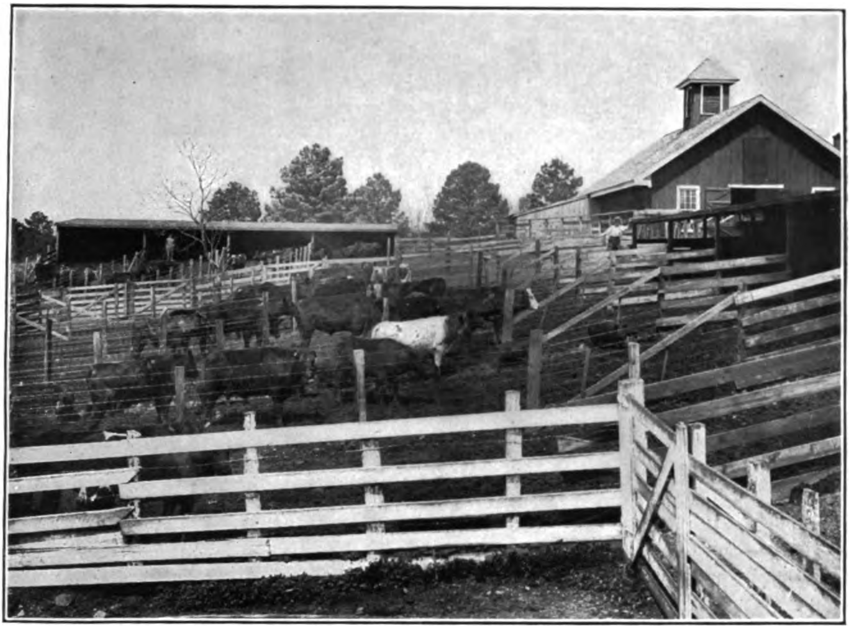

FIG. 1.—STEERS IN FEED LOTS—FIRST EXPERIMENT.

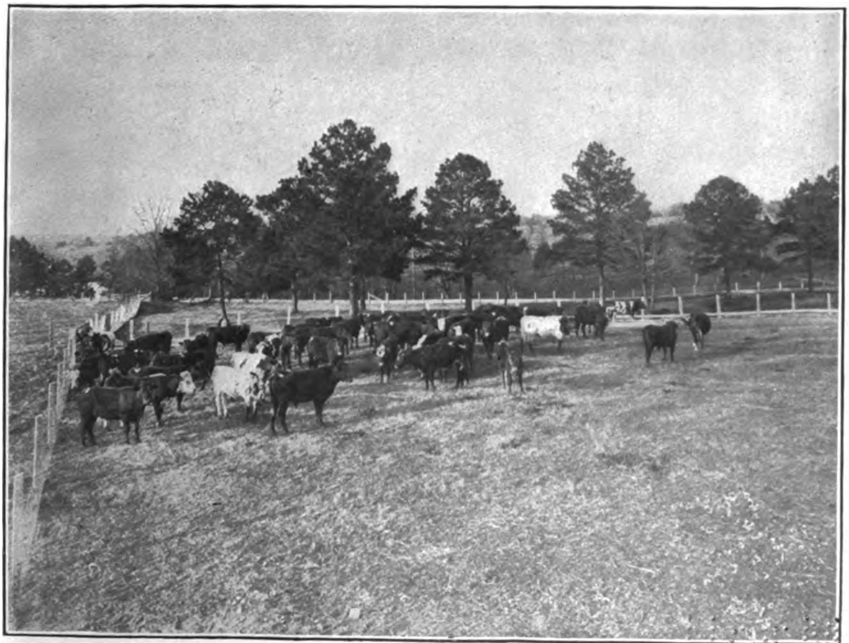

FIG. 2.—GENERAL VIEW OF STEERS IN SECOND EXPERIMENT.

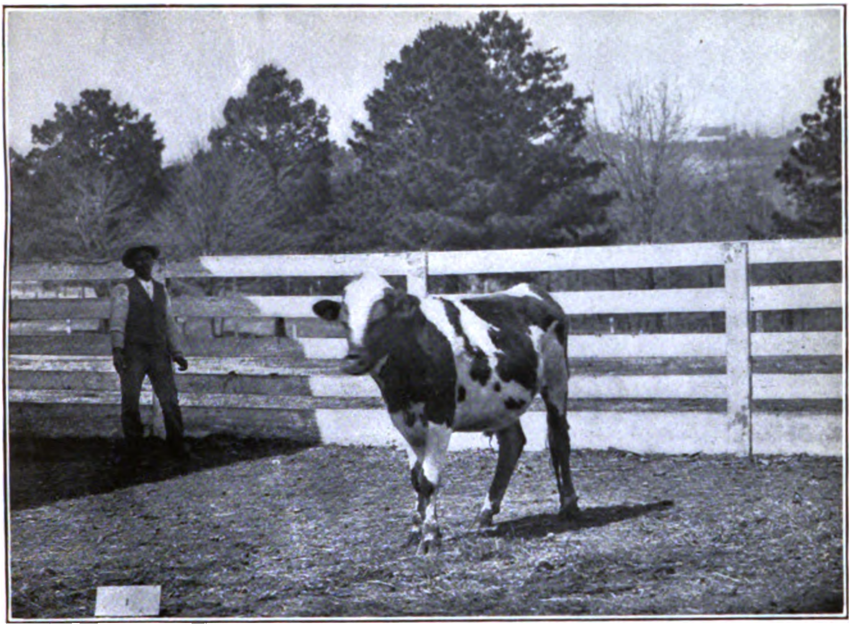

FIG. 1 —SCRUB STEER—FIRST EXPERIMENT.

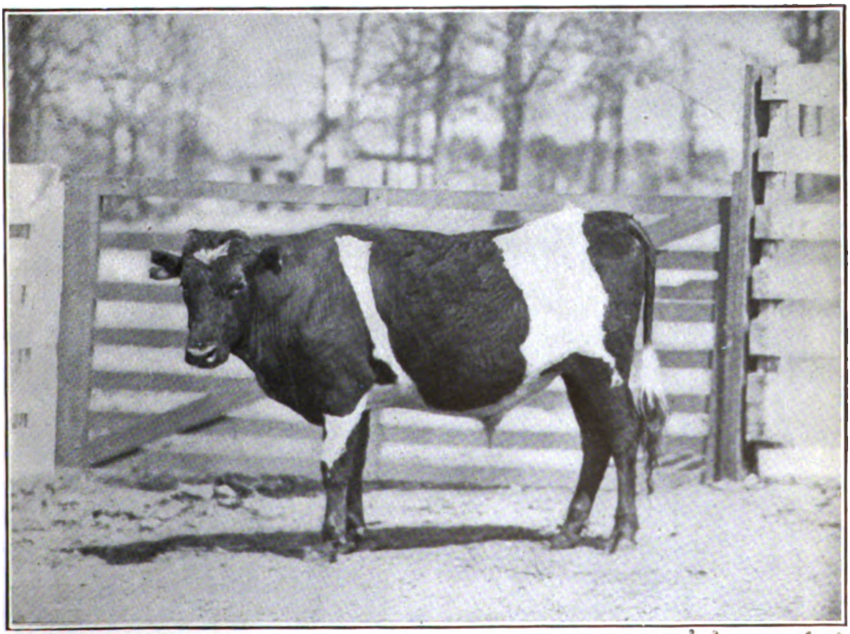

FIG. 2.—ANOTHER SCRUB STEER—FIRST EXPERIMENT.

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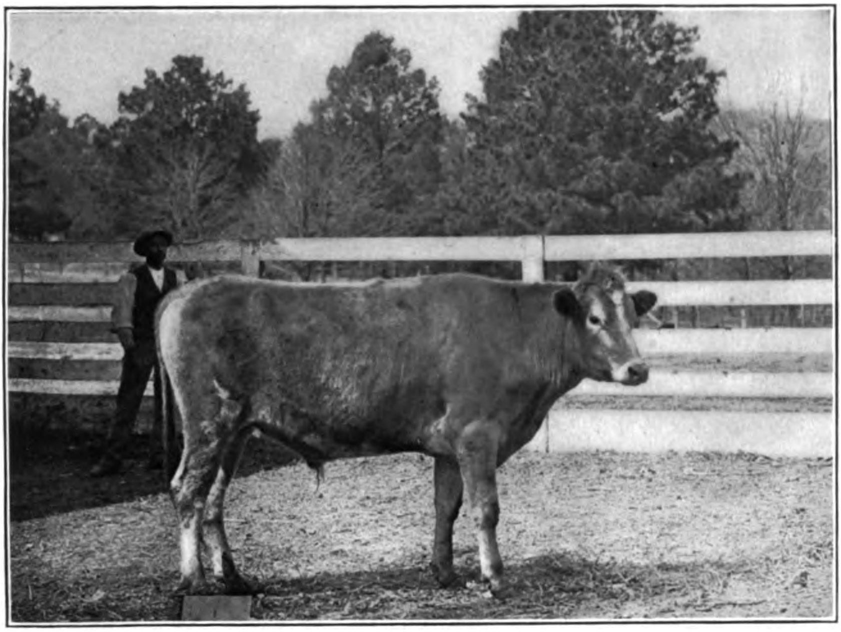

FIG. 1.—SCRUB STEER—FIRST EXPERIMENT.

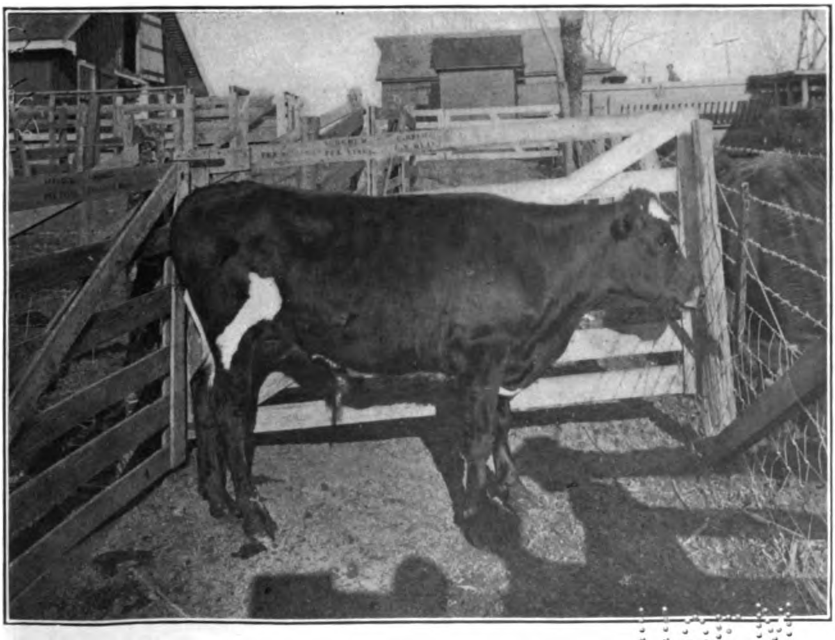

FIG. 2.—SCRUB STEER—SECOND EXPERIMENT.

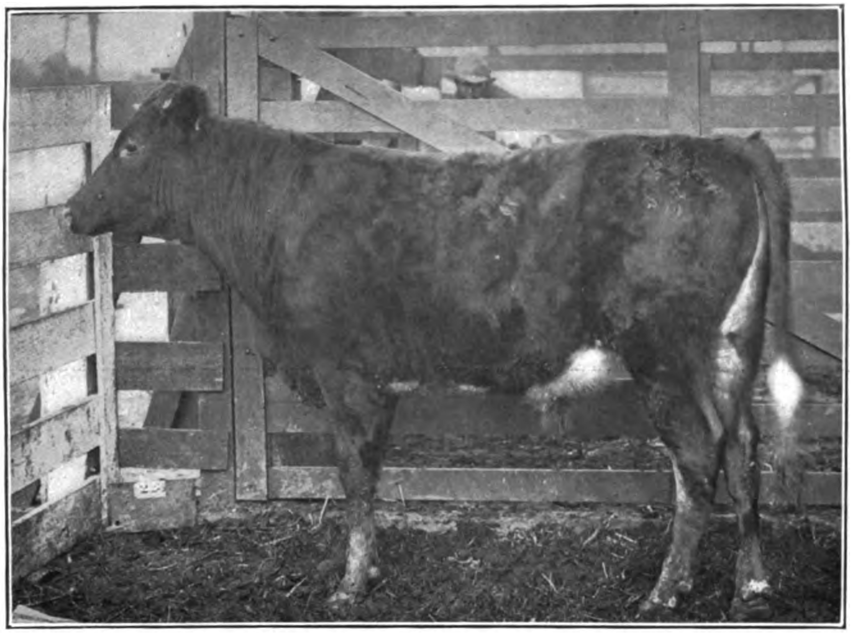

FIG. 1.—GRADE RED POLL—FIRST EXPERIMENT.

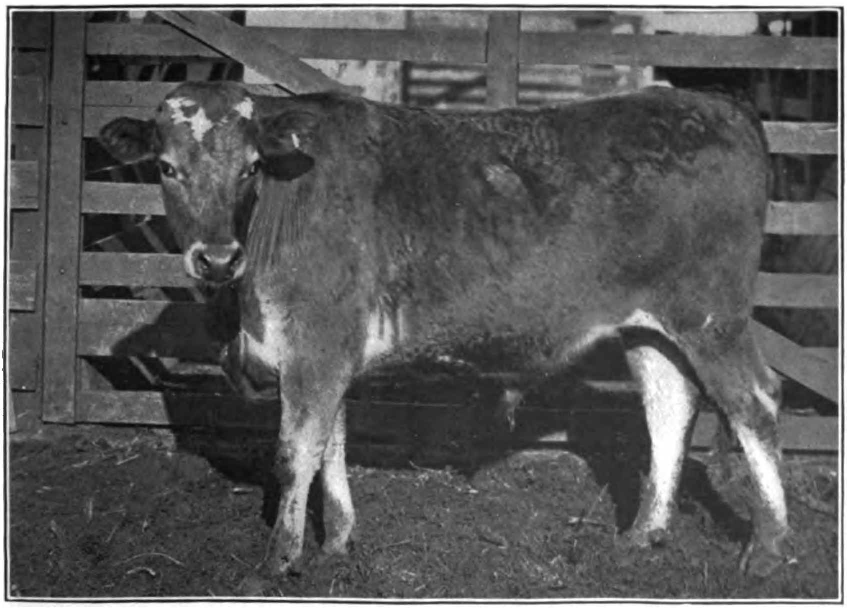

FIG. 2.—GRADE SHORTHORN—FIRST EXPERIMENT.

There was left in the troughs uneaten 29 per cent of the stover that was fed. This refuse consisted chiefly of the larger sections of the corn stalk, and, of course, its weight was charged to the steers. This waste material was removed from the troughs when necessary and used as bedding.

The sorghum forage fed varied considerably in different years, but was on the whole very inferior, being chiefly coarse and sometimes slightly moldy. Ten per cent of it was left in the troughs. The cowpea hay was below average quality, by reason of the fact that it contained a small amount of crab grass. The sorghum was cut into lengths of about three-fourths of an inch, but the cowpea hay was fed whole.

During the course of each experiment the local prices of corn and cotton-seed meal and hulls were abnormally high. The average market prices for the three years were approximately as follows:

	Per ton.
Cotton-seed meal	$24.00
Cotton seed	14.00
Corn (70 cents a bushel)	25.00
Corn-and-cob meal (corn 70 cents a bushel)	20.00
Cotton-seed hulls	7.00
Corn stover (home grown; unbaled; estimated)	4.00
Sorghum fodder (home grown; unbaled; estimated)	6.67
Cowpea hay (home grown; unbaled; estimated)	10.00

Since the prices prevailing while these experiments were in progress were unusually high, the figures given above may be regarded as representing nearly the upper limit of prices for purchased feeds and the market value of the farm-grown roughage unbaled on the farm. By contracting in the summer for the necessary amounts, the purchasable feed can sometimes be obtained at about the following prices:

	Per ton.
Cotton-seed meal	$20.00
Cotton seed	12.00
Corn-and-cob meal (corn 50 cents per bushel)	14.67
Cotton-seed hulls	4.00
Corn stover (home grown)	4.00
Sorghum fodder (home grown)	6.67
Cowpea hay (home grown)	10.00

Unless otherwise stated, all financial calculations in this bulletin are based on the last-named prices. The prices of the roughage grown on the farm would be much lower and the profits much greater than calculated in this bulletin if we could assume as the price of the stover and hay the actual cost of growing it. Unfortunately, there are no adequate data on record to establish the cost of growing a ton of each of these feeds.

THE RATIONS.

The rations fed to the various pens are shown in Table 1.

TABLE 1.—*The ration fed to each pen.*

Pens and steers.	Concentrate.	Roughage.
Pen 1 (scrubs)	Cotton-seed meal	Cotton-seed hulls.
Pen 2 (grades)	do	Do.
Pen 3 (grades)	⅔ cotton-seed meal, ⅓ corn-and-cob meal.	Do.
Pen 4 (grades)	Cotton-seed meal	Shredded corn stover.
Pen 5 (grades)	do	Cut sorghum.
Pen 6 (grades; no shelter)	do	Cotton-seed hulls.
Pen 7 (grades)	⅔ cotton-seed meal, ⅓ corn-and-cob meal.	Shredded corn stover.
Pen 8 (grades)	⅔ cotton seed, ⅓ cotton-seed meal	½ cowpea hay, ½ sorghum.
Pen 9 (grades)	⅔ cotton seed, ⅓ corn-and-cob meal	Do.
Pen 10 (grades)	⅔ corn-and-cob meal, ⅓ cotton-seed meal.	Do.

HOGS FOLLOWING THE STEERS.

Very little corn being fed, and that being ground, hogs did not follow the steers except in the first winter. They made such slight gains that the inconvenience of having them in the pens was regarded as counterbalancing the gains made. Ten pigs, averaging 81 pounds live weight when put in the pens, followed the 50 steers for seventy-one days. They had access to all pens and received about 2 pounds of shelled corn per day. The average gains were 0.45 pound per day per pig, requiring 2.5 pounds of shelled corn to make 1 pound of gain. It appears that they made about half their living on the droppings. No pig showed any signs of cotton-seed meal poisoning, in spite of the fact that they often got into the steers' feed troughs. The pigs cost 4½ cents a pound and sold in New Orleans at 5½ cents a pound, live weight, March 28, 1905. The net profit per pig, with corn at 50 cents a bushel, was $1.20.

COMPARISON OF DAILY GAINS.

Sorghum versus cotton-seed hulls (*pens 2 and 5*).—Comparing the daily gains, as shown in Table 2, of the pen fed on cut sorghum (pen 5) with those made by the check lot on cotton-seed hulls (pen 2), we find that cotton-seed hulls afforded larger daily gains in the second and third years and practically identical gains in the first winter. The lower average daily gain with sorghum (1.39 pounds, as compared with 1.55 pounds from feeding hulls) is believed to be partly due to the smaller amount of sorghum than of hulls consumed.

It should be mentioned that the selling price per hundredweight of the steers fed on sorghum was, each year, a little below the price of those fed on hulls.

Shredded corn stover versus cotton-seed hulls (pens 2 and 4).—Comparing shredded corn stover (pen 4) with the check lot fed on cotton-seed hulls (pen 2), we find in all three experiments that the daily gains were more rapid where the hulls were fed. The average daily gain for the three years with stover was only 1.19 pounds, as compared with 1.55 pounds when cotton-seed hulls were fed. This may have been due to the fact that the steers could not be induced to eat as much stover as hulls.

Cotton seed versus corn-and-cob meal as the principal concentrate (pens 8 and 10).—The average daily gain for the three years is very slightly in favor of pen 10, fed chiefly on corn-and-cob meal. However, as this difference in rapidity of gain represents less than 2 per cent, and since cotton seed was ahead in one of the three experiments, we are justified in regarding these experiments as indicating that a pound of cotton seed was practically equal to a pound of corn-and-cob meal.

Cotton-seed meal versus corn-and-cob meal as an appetizer when fed in connection with cotton seed (pens 8 and 9).—In the preceding paragraph, the corn and cotton seed constituted two-thirds of the weight of the concentrate. We now make a comparison between rations in which cotton-seed meal and corn-and-cob meal made up only one-third of the ration.

The average results for three years are in favor of cotton-seed meal as a supplementary feed. Pen 8, which received cotton-seed meal mixed with cotton seed, gave an average daily gain of 1.68 pounds, as compared with 1.52 pounds for pen 9, which received corn-and-cob meal mixed with cotton seed. However, the results of the three different experiments are not in accord.

Effect of substituting corn-and-cob meal for one-third of the cotton-seed meal when fed with (a) hulls or (b) corn stover (pens 2 and 3, and 4 and 7).—(*a*) Pen 2 was fed, as is common in the South, on a ration of cotton-seed meal and cotton-seed hulls. Pen 3 was similarly fed, except that corn-and-cob meal was substituted, pound for pound, for one-third of the cotton-seed meal, thus widening the nutritive ratio. The average results for three years show a slightly more rapid gain from the use of corn-and-cob meal. In two of the experiments corn-and-cob meal afforded the more rapid gain, while in the third experiment the rates of gain were identical for the two rations.

(*b*) Likewise corn-and-cob meal was substituted, pound for pound, for one-third of the cotton-seed meal where the roughage was shredded corn stover (pens 4 and 7). The result in this case was also favorable to the use of corn-and-cob meal, the average daily gain being slightly larger for pen 7, receiving a partial ration of corn-and-cob meal, than for pen 4, receiving only cotton-seed meal as a concentrate.

TABLE 2.—*Average daily gains and consumption.*

Pen No.	Ration.		Average daily gain, 1904–5 (84 days).	Average daily gain, 1905–6 (84 days).	Average daily gain, 1906–7 (84 days).	Average daily gain, whole period (252 days).	Average amount consumed per steer per day, whole period.	
	Concentrate.	Roughage.					Concentrate.	Roughage.
			Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1 (scrubs.)	Cotton-seed meal	Cotton-seed hulls	2.20	1.55	1.30	1.68	5.1	18.5
2	do	do	1.88	1.51	1.27	1.55	5.6	19.5
3	⅔ cotton-seed meal ⅓ corn-and-cob meal.	do	1.93	1.87	1.27	1.69	6.5	19.4
4	Cotton-seed meal	Shredded corn stover.	1.84	1.15	.57	1.19	5.5	17.4
5	do	Cut sorghum	1.89	1.12	1.17	1.39	5.5	15.9
6	do	Cotton-seed hulls	1.62	1.29	1.50	1.47	5.5	21.3
7	⅔ cotton-seed meal ⅓ corn-and-cob meal.	Shredded corn stover.	1.77	1.29	.90	1.32	6.5	16,6
8	⅔ cotton seed ⅓ cotton-seed meal	½ cowpea hay ½ cut sorghum	1.85	2.00	1.19	1.68	7.1	15.6
9	⅔ cotton seed ⅓ corn-and-cob meal.	½ cowpea hay ½ cut sorghum	2.10	1.48	.99	1.52	7.2	14.9
10	⅔ corn-and-cob meal. ⅓ cotton-seed meal	½ cowpea hay ½ cut sorghum	2.10	1.70	1.34	1.71	7.2	16.1

Effects of shelter.—The animals in pen 2 were fed under an open shed, and pen 6 had no shelter. The average daily gain for the three years was 1.55 pounds for the pen under shelter and 1.47 pounds for the lot without shelter. In the two wet winters (1904–5 and 1905–6) the largest daily gains were made by the lot under shelter; but in the mild and rather dry winter of 1906–7 the lot without shelter made more rapid gains.

Scrubs versus grades.—Pen 1 consisted of scrubs—that is, of native cattle without admixture of any improved beef blood. Pen 2 contained grades of the beef and dual-purpose breeds as described on page 11. The scrubs made an average gain for three years of 1.68 pounds and the grades an average daily gain of 1.55 pounds. In the first experiment the scrubs were notably thinner than the grades at the beginning of the feeding period, and hence the scrubs made more rapid gains. In the other two experiments the scrubs and the grades made almost identical daily gains.

FEED REQUIREMENTS.

Sorghum versus cotton-seed hulls (pens 2 and 5).—The average of three years' results shows that 1 pound of gain was made with the consumption of only 3.66 pounds of concentrated feed in the case of the lot getting cotton-seed hulls, as compared with 4.23 pounds for the lot fed on sorghum. Every year there was a smaller consumption of roughage per pound of gain in the sorghum lot than in the lot fed on hulls, the figures being, respectively, 11.95 and 13.47 pounds of roughage. Special attention is called to the very small amounts of

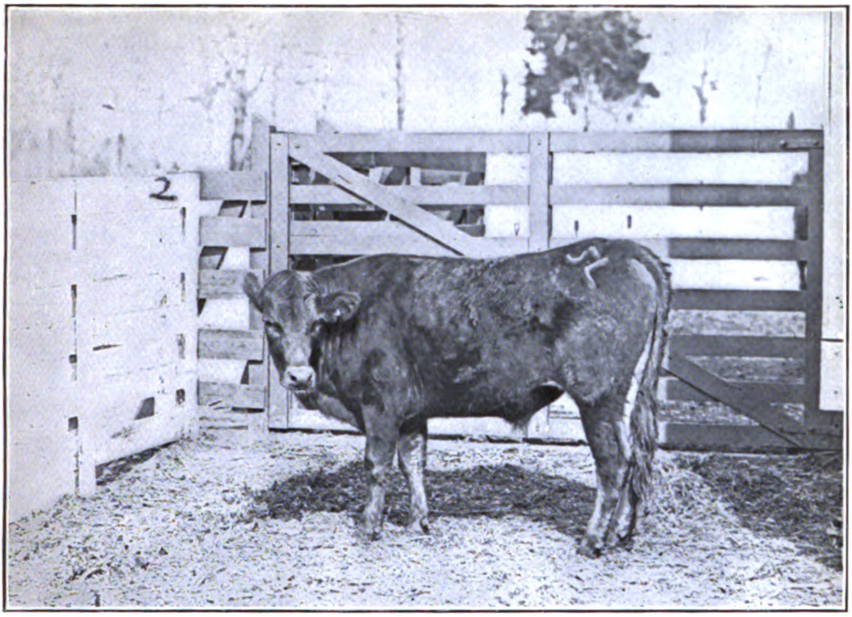

FIG. 1.—GRADE RED POLL—FIRST EXPERIMENT.

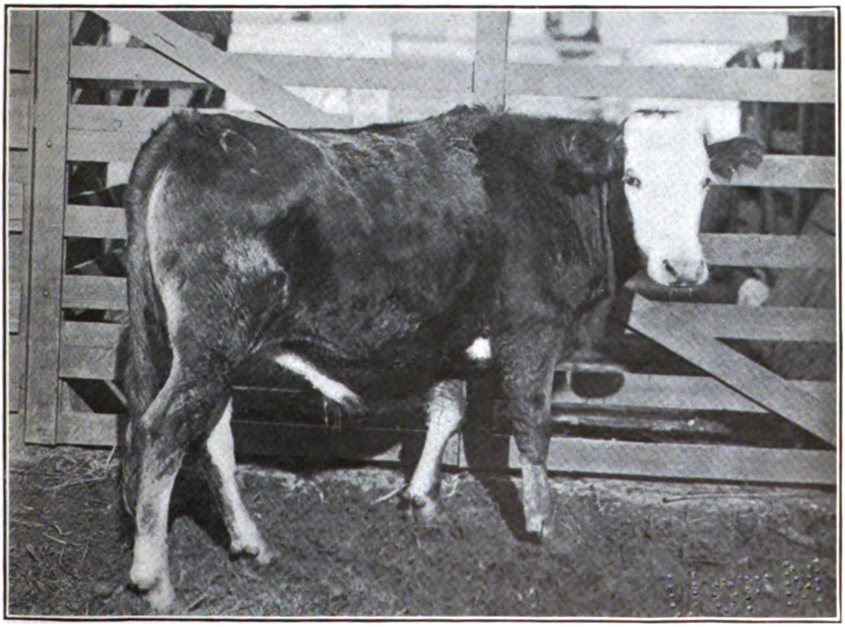

FIG. 2.—GRADE HEREFORD—FIRST EXPERIMENT.

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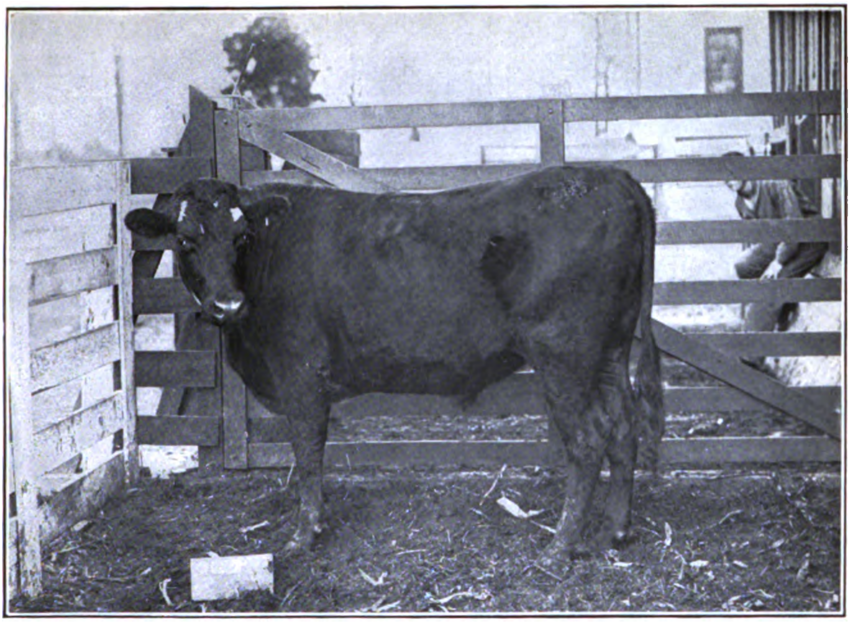

FIG. 1.—GRADE ABERDEEN-ANGUS STEER—FIRST EXPERIMENT.

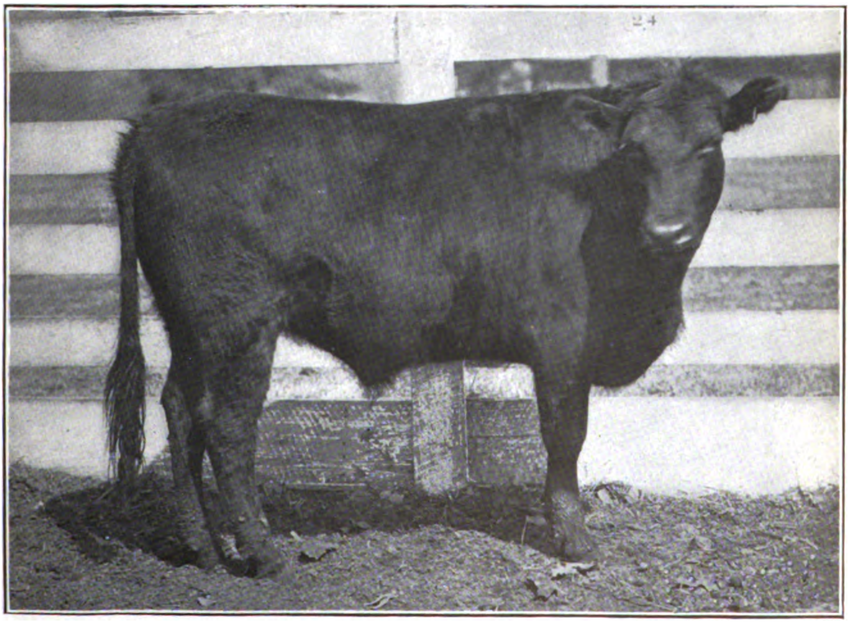

FIG. 2.—GRADE ABERDEEN-ANGUS STEER—FIRST EXPERIMENT.

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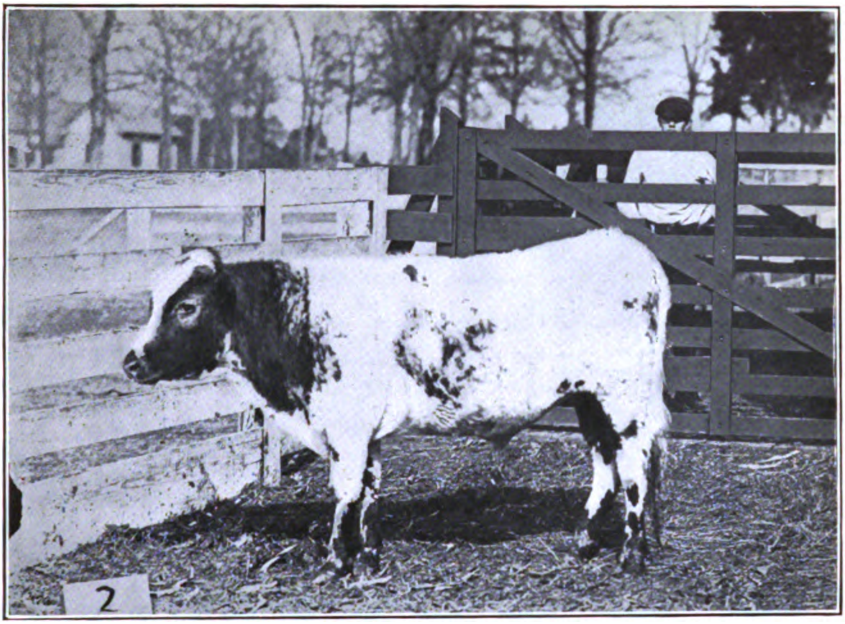

FIG. 1.—GRADE SHORTHORN—FIRST EXPERIMENT.

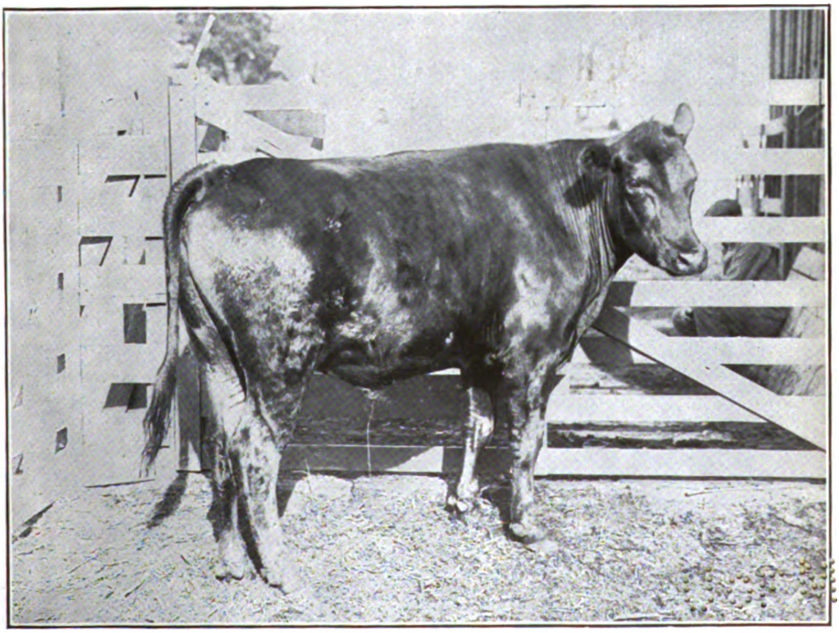

FIG. 2.—GRADE ABERDEEN-ANGUS—FIRST EXPERIMENT.

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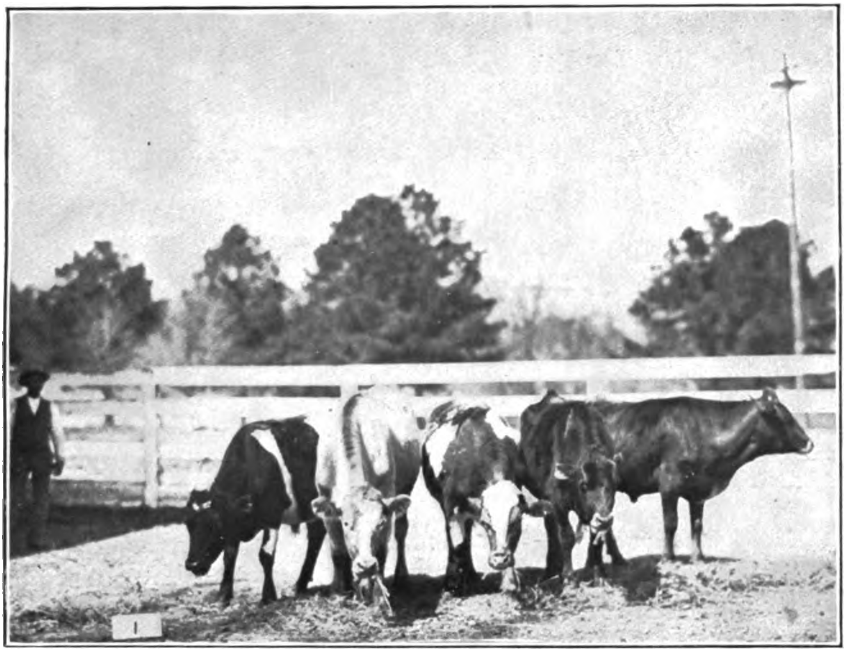

FIG. 1.—PEN OF SCRUBS—FIRST EXPERIMENT.

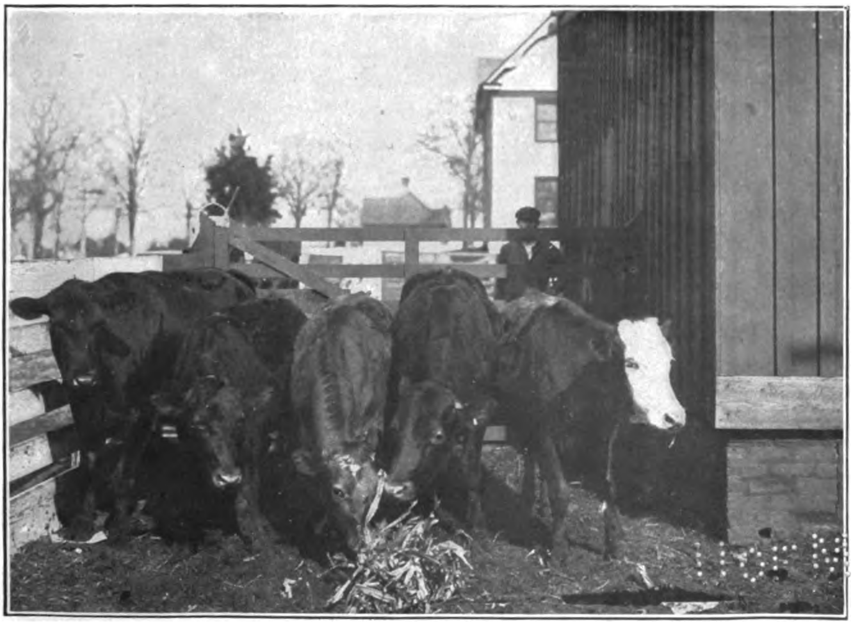

FIG. 2.—PEN OF GRADES—FIRST EXPERIMENT.

concentrated feed (cotton-seed meal) required to make 1 pound of gain. When corn alone is fed in the corn belt the amount required is often 10 to 13 pounds of corn for each pound gain in live weight. In this experiment pen 2 required only about one-third the usual amount of concentrate to produce a pound of increase in live weight, which emphasizes the relatively high fattening value of cotton-seed meal.

Corn stover versus cotton-seed hulls (pens 2 and 4).—When corn stover was fed ad libitum together with a limited amount of cotton-seed meal it required 5.78 pounds of concentrate for 1 pound of gain, as compared with 3.66 pounds of cotton-seed meal when fed in connection with hulls. In the same rations it required for 1 pound of growth 18.47 pounds of shredded corn stover as compared with only 13.47 pounds of cotton-seed hulls. In other words, it required 59 per cent more of cotton-seed meal to make 1 pound of gain when fed with stover than when fed with hulls. Moreover, to make 1 pound of gain there was required 37 per cent more stover than hulls.

Cut sorghum versus shredded corn stover (pens 4 and 5).—Comparing the amounts of these two feeds to make a pound of gain, there was required only 11.95 pounds of sorghum as compared with 18.47 pounds of stover, or 54 per cent more of stover. To produce the same effect required only 4.23 pounds of cotton-seed meal when fed with sorghum as compared with 5.78 pounds of cotton-seed meal when fed with stover, or 37 per cent more concentrate in the stover ration.

Cotton-seed meal versus corn-and-cob meal as the principal concentrate (pens 8 and 10).—Taking the average figure for the three experiments, the amount of concentrate required to produce a pound of gain in a ration consisting chiefly of cotton seed was 4.39 pounds as compared with 4.29 pounds of concentrate in a ration consisting chiefly of corn-and-cob meal. With the corn there was a slightly less roughage (mixed hay) required. However, these differences were both less than 2.5 per cent, so that we may properly interpret these results as showing practical equality in the nutritive effect of cotton-seed and corn-and-cob meal, pound per pound.

Cotton-seed meal versus corn-and-cob meal as a supplementary feed with cotton seed (pens 8 and 9).—When only one-third of the ration consisted of cotton-seed meal or corn-and-cob meal, used to make cotton seed more palatable, there were required 17 per cent more concentrate and 10 per cent more roughage to make 1 pound gain in the ration containing corn-and-cob meal. In other words, cotton-seed meal was slightly more efficient than corn-and-cob meal, when used as a supplementary concentrate or appetizer.

Effect of substituting corn-and-cob meal for one-third of the cotton-seed meal when fed with (a) hulls or (b) corn stover (pens 2 *and 3, and 4 and 7)*.—(*a*) When hulls constituted the roughage the substitution of corn for one-third of the cotton-seed meal slightly increased the amount of concentrate required per pound of gain (3.66 pounds to 3.96 pounds) and slightly reduced the amount of hulls required per pound of gain (from 13.47 pounds to 11.91 pounds). This shows that the substitution of corn and the consequent widening of the nutritive ratio effected practically no economy in the feed required.

(*b*) When a similar substitution was made in a ration in which the roughage was shredded corn stover, this substitution of corn-and-cob meal for an equal weight of cotton-seed meal gave contradictory results in the different experiments.

Effect of shelter (pens 2 and 6).—In two experiments out of three and in the average for three years, shelter resulted in a slight economy in use of concentrated feed and a slight loss in the use of roughage. In other words, shelter on the whole saved 0.2 of a pound of cotton-seed meal per pound gain and lost 0.49 of a pound of roughage. The steers out of doors consumed a larger ration of roughage.

Scrubs versus grades (pens 1 and 2).—The averages agree with each of the three experiments in showing that the scrubs required slightly less concentrate and roughage to make 1 pound of gain than did the grades. These results are chiefly due to the fact that in the first year's experiments the scrubs were thinner than the grades. In the other two years there was practically no difference in condition at the beginning of the experiment and very little in economy of feed.

TABLE 3.—*Feed required to make 1 pound of gain.*

No. of pen.	Ration.		1904–5			1905–6		
	Concentrate.	Roughage.	Average daily gain per steer.	Pounds of food required per pound of gain.		Average daily gain per steer.	Pounds of food required per pound of gain.	
				Concentrate.	Roughage.		Concentrate.	Roughage.
1	Cotton-seed meal	Cotton-seed hulls	2.20	1.90	8.36	1.55	3.92	10.57
2	do	do	1.88	2.75	9.75	1.51	4.16	14.27
3	⅔ cotton-seed meal, ⅓ corn-and-cob meal.	do	1.93	3.06	9.52	1.87	3.89	10.94
4	Cotton-seed meal	Shredded corn stover.	1.84	2.78	9.59	1.15	5.47	14.82
5	do	Cut sorghum	1.89	2.70	8.64	1.12	5.53	13.06
6	do	Cotton-seed hulls	1.62	3.14	11.45	1.29	4.84	13.86
7	⅔ cotton-seed meal, ⅓ corn-and-cob meal.	Shredded corn stover.	1.77	3.33	8.68	1.29	5.68	12.84
8	⅔ cotton seed, ⅓ cotton-seed meal.	½ sorghum, ½ pea hay.	1.85	3.69	8.52	2.00	3.86	7.91
9	⅔ cotton seed, ⅓ corn-and-cob meal.	do	2.10	3.37	7.37	1.48	5.19	9.40
	corn-and-cob meal, ⅓ cotton-seed meal.	do	2.10	3.37	7.92	1.70	4.51	9.26

TABLE 3.—*Feed required to make 1 pound of gain*—Continued.

No. of pen.	Ration.		1906–7			Average for 3 experiments.		
	Concentrate.	Roughage.	Average daily gain per steer.	Pounds of food required per pound of gain.		Average daily gain per steer.	Pounds of food required per pound of gain.	
				Concentrate.	Roughage.		Concentrate.	Roughage.
1	Cotton-seed meal	Cotton-seed hulls	1.30	4.01	16.06	1.68	3.28	11.66
2	do	do	1.27	4.08	16.39	1.55	3.66	13.47
3	⅔ cotton-seed meal, ⅓ corn-and-cob meal.	do	1.27	4.94	15.26	1.69	3.96	11.91
4	Cotton-seed meal	Shredded corn stover.	.57	9.10	31.00	1.19	5.78	18.47
5	do	Cut sorghum	1.17	4.45	14.15	1.30	4.23	11.95
6	do	Cotton-seed hulls	1.50	3.59	13.61	1.47	3.80	12.98
7	⅔ cotton-seed meal, ⅓ corn-and-cob meal.	Shredded corn stover.	.90	7.00	19.88	1.32	5.32	13.80
8	⅔ cotton seed, ⅓ cotton-seed meal.	½ sorghum, ½ pea hay.	1.19	5.63	12.97	1.68	4.39	9.80
9	⅔ cotton seed, ⅓ corn-and-cob meal.	do	.90	6.80	15.54	1.52	5.12	10.77
10	⅔ corn-and-cob meal, ⅓ cotton-seed meal.	do	1.34	5.00	11.81	1.71	4.29	9.66

FINANCIAL STATEMENT.

Table 4 shows the average, for three years, of the weights of the steers at the beginning and end of the experiment proper, the shrinkage in shipment, the average selling price in New Orleans, the average shipping and selling expenses per steer, the total cost of feed at high and at low prices (see p. 13), and the gain or loss per steer (exclusive of manure) calculated for both high and low prices of feed.

TABLE 4.—*Weights, shrinkage, and financial statement* (*average for three years*).

No. of pen.	Average weight per steer at beginning of experiment.	Average weight per steer at Auburn at end of experiment.	Shrinkage per steer in shipping.	Selling price per hundredweight at New Orleans.	Shipping expenses per steer.	Total cost of feed per steer at high price of feed.	Total cost of feed per steer at low price of feed.	Loss per steer at high price of feed.	Profit (+) or loss (−) per steer at low price of feed.
	Pounds.	*Pounds.*	*Pounds.*						
1	654	795	92	$4.05	$3.27	$10.62	$7.42	$1.78	+$1.42
2	734	865	82	4.42	3.27	11.36	7.96	2.05	+ 1.34
3	737	878	86	4.32	3.27	11.80	8.34	2.93	+ .53
4	708	808	63	4.11	3.27	8.49	7.56	2.40	− 1.47
5	698	815	67	4.18	3.27	10.01	9.09	2.92	− 2.00
6	714	837	73	4.20	3.27	11.02	7.81	3.14	+ .07
7	689	799	69	3.97	3.27	8.95	7.87	4.16	− 3.07
8	700	841	74	4.19	3.27	10.61	9.41	2.77	− 1.58
9	688	816	72	4.12	3.27	10.05	8.62	3.33	− 1.90
10	722	866	82	4.25	3.27	12.04	10.50	3.68	− 2.13

Shrinkage.—The shrinkage in shipping to market in New Orleans was in all three experiments larger than it would have been under normal conditions. In the absence of facilities for loading cattle at Auburn the steers at the end of the first experiment had to be driven 7 miles before being loaded. In the second and third experiments there were unusual delays in transportation; in one case the steers were on the road forty-two hours between Auburn and New Orleans (a distance of 380 miles), because of delayed trains and a strike of railroad switchmen in New Orleans. If the steers had reached their destination on schedule time, which is about nineteen hours after leaving Auburn, the shrinkage would undoubtedly have been less and the financial results more favorable. To prepare the steers for shipment, they were all put on a ration consisting chiefly of hay for one day before leaving Auburn.

It is interesting to note that cotton seed, although a very laxative food, did not increase the amount of shrinkage of pens 8 and 9 as compared with other feeds. The steers fed on corn stover (pens 4 and 7) shrunk least.

Average selling price in New Orleans.—Taking the average selling price in New Orleans for the three experiments, we find that the highest average return was $4.42 per hundredweight, for pen 2, consisting of grade steers fed exclusively on cotton-seed meal and hulls. The next highest price, $4.32, was obtained for pen 3, in which corn-and-cob meal was substituted for a part of the cotton-seed meal. The third highest price, $4.29 per hundredweight, was paid for pen 6, fed without shelter on cotton-seed meal and hulls. This is a reduction in price of 13 cents per hundredweight as the apparent loss from feeding in the open. This was due to the steers without shelter having a rougher, duller coat.

The steers getting corn-and-cob meal (pen 10) as the principal concentrate sold a little higher than those fed on cotton seed, but not as high as those fed on cotton-seed meal and hulls. The steers from pens 4 and 7, getting corn stover as roughage, sold lower than any of the other grades, not being so fat. Pen 5, getting sorghum as roughage, sold better than the stover pens and about the same as the pens getting cotton seed and hay, but not so well as the others.

The scrubs (pen 1) sold for about two-thirds of a cent less per pound than grades getting the same ration, and sold lower than any others except pen 7, fed stover for roughage. They were probably a little fatter than most of the grades because they were older and had fattened during the experiment instead of growing, as some of the younger grades had done.

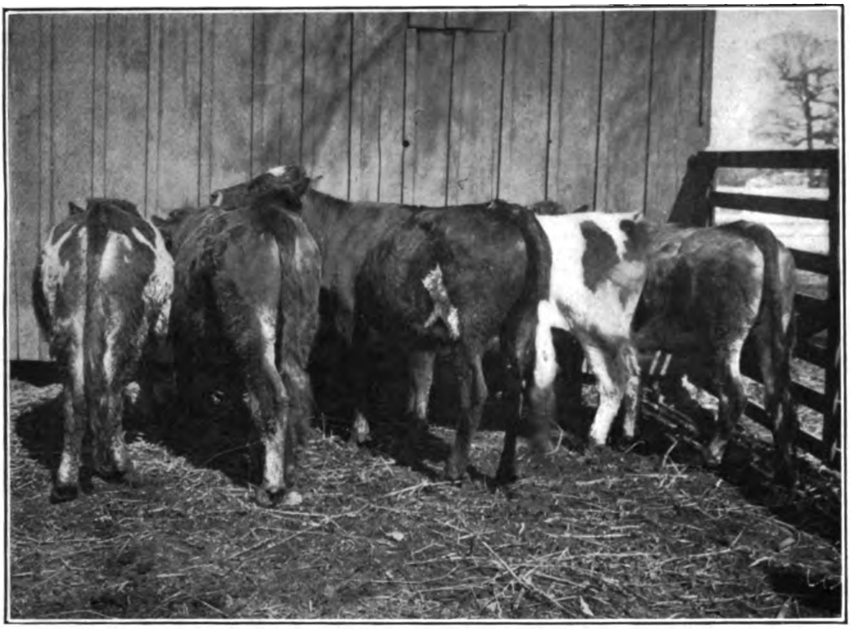

FIG. 1.—PEN OF SCRUBS—SECOND EXPERIMENT.

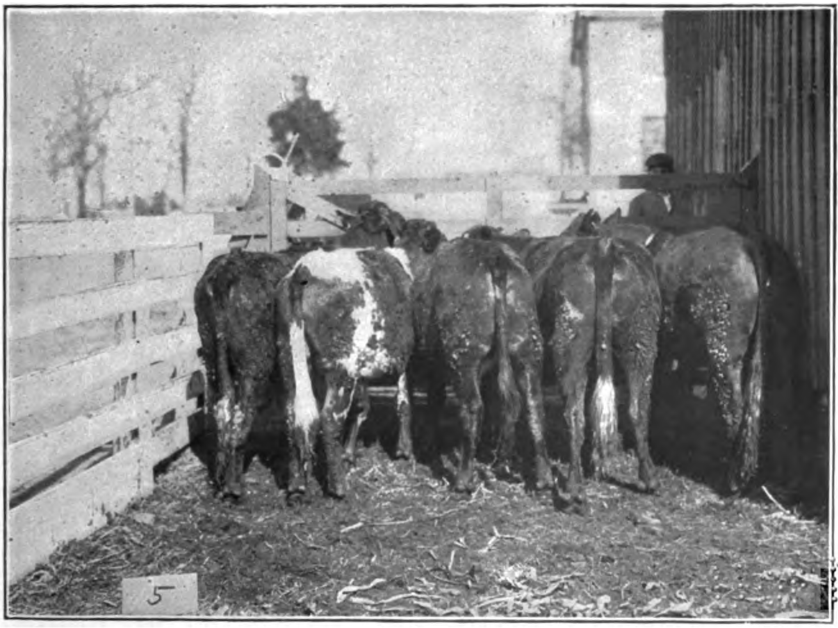

FIG. 2.—PEN OF GRADES—FIRST EXPERIMENT.

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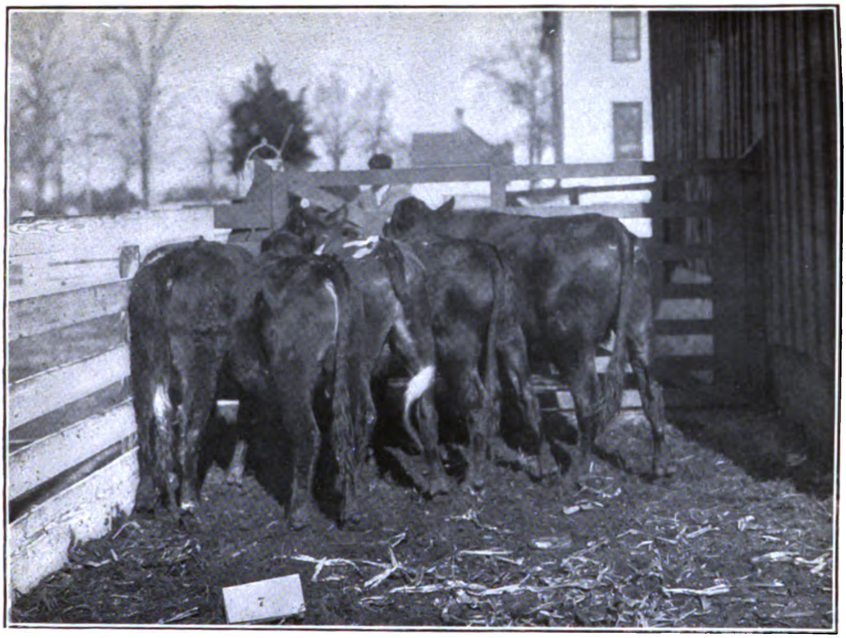

FIG 1.—PEN OF GRADES—FIRST EXPERIMENT.

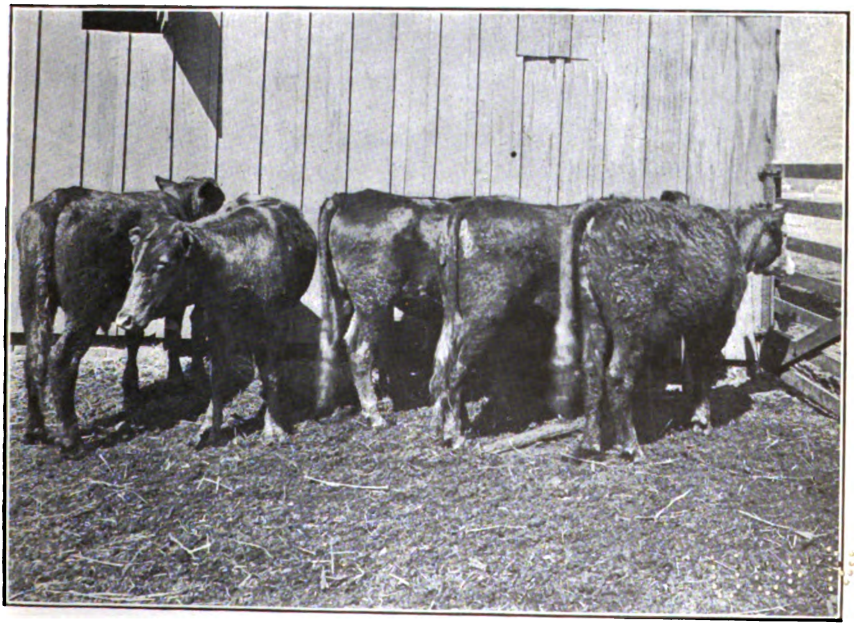

FIG. 2.—PEN OF GRADES—SECOND EXPERIMENT.

Profit or loss per steer.—Taking no account of the value of the manure and no account of the gains made by the hogs that followed the steers the first winter, we find that with cotton-seed meal at $24 per ton, hulls at $7 per ton, and corn at 70 cents per bushel, there was in every combination of these and other feeds a financial loss. This simply shows that such prices are too high to permit profitable feeding in such rations as those used, unless the margin between the buying and selling price of steers should be wider than it was in these experiments, namely, from about one-fourth to about three-fourths of a cent per pound. (See Table 6.)

A somewhat better financial showing is made when we figure with the more reasonable prices for the purchased feeds and the same prices as before for the home-grown stover, sorghum, and cowpea hay (p. 22). On this basis a small profit was made on all the steers that received cotton-seed hulls. On all other pens there was still a financial loss, chiefly due to the relatively high price which we have assumed for sorghum and cowpea hay in the absence of any data showing the exact cost of producing this roughage.

On the basis of prices just assumed, the greatest profit, $1.42 per steer, was made by the scrubs, because they were bought at a lower price per pound, thus giving a larger margin (77 cents per hundredweight), as shown in Table 6.

Comparing the financial results for the nine pens of grades, we find that the only three showing a profit rank as follows:

1. Pen 2, fed on cotton-seed meal and hulls.
2. Pen 3, fed on two-thirds cotton-seed meal and one-third corn-and-cob meal and hulls.
3. Pen 6, fed or cotton-seed meal and hulls (without shelter).

The feeding of hulls was more profitable than feeding stover at the same price (pens 2 and 4, and 3 and 7). Cotton seed was a more economical ration than corn (pens 8 and 10).

Cotton-seed meal was more economical than corn-and-cob meal as a supplementary feed with cotton seed. It was slightly more profitable to feed cotton-seed meal as the sole concentrate than to substitute for one-third of the cotton-seed meal an equal weight of corn-and-cob meal. This was true whether the roughage consisted of hulls or corn stover.

Returns received for roughage fed.—Table 5 shows the actual value in beef received as the return obtained from feeding 1 ton of the several kinds of roughage. This is based upon the difference between the selling price of the steers and the purchase price plus the cost of the concentrate fed to each pen. The figures given in the first two columns are based upon prices of $20 a ton for cotton-seed meal, $12 a ton for cotton seed, and 50 cents a bushel for corn.

This table shows that on this basis the average financial return per ton of roughage, excluding the value of the manure, was as follows:

Cotton-seed hulls, $4.64 to $5.82 per ton.

Cut sorghum fodder alone, $3.68 per ton.

Mixed sorghum and cowpea hay, $5.18 to $5.92 per ton.

Corn stover when fed with cotton-seed meal alone returned only $1.98 per ton.

These figures suggest that under conditions prevailing in this experiment, and with cotton-seed meal at $20 a ton a farmer could afford to give $4.64 to $5.82 a ton for hulls and have manure to offset labor of feeding, interest on investment, and profit. A quarter of a cent margin in addition to what was received would enable one to pay a considerably higher price for feed or greatly to increase the profit of feeding.

TABLE 5.—*Actual value of roughage for feeding (average for three years).*

No. of pen.	Ration.		Cost of all steers per pen and of grain fed.	Cost of steers per hundredweight.	Selling price per hundredweight at Auburn.[a]	Selling price per pen at Auburn.[a]	Difference, equivalent to value of roughage fed.	Roughage consumed (pounds).	Value of roughage per ton.
	Concentrate.	Roughage.							
1	Cotton-seed meal......	Cotton-seed hulls	$103.32	$2.50	$3.27	$125.97	$22.65	7,778	$5.82
2	.....do..................	.....do...........	133.50	3.00	3.74	156.61	23.11	8,200	5.64
3	⅔ cotton-seed meal, ⅓ corn-and-cob meal.	.....do...........	135.91	3.00	3.63	154.83	18.92	8,145	4.64
4	Cotton-seed meal......	Shredded corn stover.	129.41	3.00	3.49	136.67	7.26	7,314	1.98
5	.....do..................	Cut sorghum.....	127.86	3.00	3.54	140.13	12.27	6,679	3.68
6	.....do..................	Cotton-seed hulls	130.47	3.00	3.62	146.92	16.45	7,855	4.19
7	⅔ cotton-seed meal, ⅓ corn-and-cob meal.	Shredded corn stover.	128.74	3.00	3.28	127.28	−1.46	6,958	− .42
8	⅔ cotton seed, ⅓ cotton-seed meal.	½ pea hay, ½ sorghum.	124.83	3.00	3.54	144.20	19.37	6,538	5.92
9	⅔ cotton seed, ⅓ corn-and-cob meal.	.....do...........	120.21	3.00	3.46	136.80	16.59	6,261	5.30
10	⅔ corn-and-cob meal, ⅓ cotton-seed meal.	.....do...........	132.64	3.00	3.57	150.17	17.53	6,763	5.18

[a] In calculating the selling price at Auburn the actual shrinkage, which was abnormally high in this experiment (see Table 4), is disregarded and the customary local 3 per cent deduction substituted therefor. The third column of figures was obtained as follows: 3 per cent for shrinkage was deducted from the sum of the final weights at Auburn. This shrunk weight was then divided into the total amount received in three years for the separate pens of steers in New Orleans, after deducting from the gross sales the expense of shipping and selling, namely, $3.27 per steer.

Margin received and margin necessary for profit.—In Table 6 are presented average financial results for three years, each figure being the average for 15 steers. All these figures, except those in line 3, are on the basis of net prices in the feed lot at the close of the experiment.

TABLE 6.—*Market values at close of experiment and margin of profit for each lot (average for three years).*

Classification of values.	Pen 1.	Pen 2.	Pen 3.	Pen 4.	Pen 5.	Pen 6.	Pen 7.	Pen 8.	Pen 9.	Pen 10.
Market value of steers per hundredweight in feed lot[a].	$3.27	$3.74	$3.63	$3.49	$3.54	$3.62	$3.28	$3.54	$3.46	$3.57
What each would have to sell for per hundredweight in feed lot to come out even.	3.04	3.57	3.57	3.67	3.79	3.61	3.68	3.69	3.69	3.83
Margin between buying price and selling price in New Orleans	1.55	1.42	1.32	1.11	1.18	1.29	.97	1.19	1.12	1.25
Margin necessary between buying and selling price in feed lot to come out even	.54	.57	.57	.67	.79	.61	.68	.69	.69	.83
Margin per hundredweight actually received in feed lot	.77	.74	.63	.49	.54	.62	.28	.54	.46	.57
Net profit (+) or loss (−) per steer	+1.42	+1.34	+ .53	−1.47	−2.00	+ .07	−3.07	−1.58	−1.90	−2.13

Pen 1 (scrubs) fed cotton-seed meal and hulls.
Pen 2 fed cotton-seed meal and cotton-seed hulls.
Pen 3 fed two-thirds cotton-seed meal, one-third corn-and-cob meal and hulls.
Pen 4 fed cotton-seed meal and corn stover.
Pen 5 fed cotton-seed meal and cut sorghum.
Pen 6 fed cotton-seed meal and hulls (no shelter).
Pen 7 fed two-thirds cotton-seed meal, one-third corn-and-cob meal and stover.
Pen 8 fed two-thirds cotton-seed, one-third cotton-seed meal, and one-half cowpea hay and one-half cut sorghum.
Pen 9 fed two-thirds cotton seed, one-third corn-and-cob meal, one-half cowpea hay, and one-half cut sorghum.
Pen 10 fed two-thirds corn-and-cob meal, one-third cotton-seed meal, and one-half hay and one-half cut sorghum.

[a] After making allowance for (1) shipping and selling expenses on basis of full cars of 33 head per car; (2) shrinkage in shipping, and (3) a 3 per cent shrinkage usually deducted by local buyers.

The first line shows the actual market value of the steers in the feed lot at Auburn at the end of the experiment, and shows the net prices at Auburn after deducting shipping expenses, etc., and after making allowance for a 3 per cent shrinkage.

The second line shows the price at which it would have been necessary to sell the steers in the feed lots to come out even.

The third line shows the margin received on the basis of prices in New Orleans.

The fourth line teaches the important lesson of how wide a margin is necessary under these conditions between the buying and selling prices of steers in the feed lot. It indicates that in general terms a margin of 54 to 83 cents per hundredweight in the feed lot is necessary to come out even, and that a still wider margin would be needed to afford any direct profit. In case the margin is calculated on the difference between the buying price of steers at the beginning of the experiment and the selling price after shipment, the margins indicated above would have to be increased by an amount large enough to cover expenses of shipment and sale. In these experiments the expense of shipping from Auburn to New Orleans and selling amounted to a little less than half a cent a pound, in addition to shrinkage. Hence, on the basis of selling prices in New Orleans the margin necessary for our feeding operations to have come out even would have been the margin indicated in line 4, plus nearly 50 cents plus difference in shrinkage, or a total of from $1.25 to $1.51 per hundred pounds. To afford any material profit at the prices here assumed, or in case of very heavy shinkage, the feeder should receive more than these latter figures.

Line 5 shows the margin actually received between the value of the steers at the beginning and at the end of the experiment, both calculated on the basis of prices in the feed lot at Auburn. In most cases this was too small for profitable feeding.

Line 6 shows the net profit or loss per steer, which has been previously commented on.

DAILY RATIONS AND DRY MATTER REQUIRED FOR 100 POUNDS OF GAIN.

In Table 7 are shown the average amount of roughage and concentrate fed per steer daily for the three-year period. It also shows the rations on the basis of dry matter required to make 100 pounds of gain. The amount of roughage in the daily ration was largest when hulls were fed, and least when mixed hay was fed.

The least amount of concentrate was consumed when cotton-seed meal was used alone, usually from 5.1 to 5.6 pounds per day. When corn-and-cob meal was added to the cotton-seed meal, the amount of concentrate consumed was about 1 pound per day greater. When cotton seed or corn-and-cob meal constituted the principal concentrate, the daily consumption of concentrated feed was increased to 7.2 pounds.

In dry matter consumed per 100 pounds of gain, cotton-seed meal alone and a mixture of cotton-seed meal and corn-and-cob meal were practically identical when fed with hulls, but the mixture was the more effective when fed with stover. With cotton seed the addition of cotton-seed meal as a supplement was slightly more effective than an equal weight of corn-and-cob meal. Corn-and-cob meal and cotton seed were practically equally effective as the principal concentrate.

TABLE 7.—*Daily rations and dry matter per hundredweight of gain.*

No. of pen.	Daily gain per steer.	Concentrate per 100 pounds gain.	Roughage per 100 pounds gain.	Dry matter per 100 pounds gain.	Average daily ration.	
					Concentrate.	Roughage.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	1.68	328, cotton-seed meal	1,166, cotton-seed hulls	1,337.7	5.1	18.5
2	1.55	366, cotton-seed meal	1,347, cotton-seed hulls	1,533.5	5.6	19.5
3	1.69	396, ⅔ cotton-seed meal, ⅓ corn-and-cob meal.	1,191, cotton-seed hulls	1,413.2	6.5	19.4
4	1.10	578, cotton-seed meal	1,847, shredded corn stover.	2,110.2	5.5	17.4
5	1.39	423, cotton-seed meal	1,195, cut sorghum	1,398.3	5.5	15.9
6	1.47	386, cotton-seed meal	1,298, cotton-seed hulls	1,508.3	5.5	21.3
7	1.32	532, ⅔ cotton-seed meal, ⅓ corn-and-cob meal.	1,380, shredded corn stover.	1,655.4	6.5	16.6
8	1.68	439, ⅔ cotton seed, ⅓ cotton-seed meal.	980, ½ cowpea hay, ½ sorghum.	1,244.8	7.1	15.6
9	1.52	512, ⅔ cotton seed, ⅓ corn-and-cob meal.	1,077, ½ cowpea hay, ½ sorghum.	1,373.9	7.2	14.9
10	1.71	429, ⅔ corn-and-cob meal, ⅓ cotton-seed meal.	966, ½ cowpea hay, ½ sorghum.	1,210.8	7.2	16.1

Analyses of all feeds, except sorghum and shredded corn stover, taken from Henry's "Feeds and Feeding." Analyses of sorghum fodder and corn stover made by C. L. Hare, of the Alabama Experiment Station.

THE NUTRITIVE RATIO.

The nutritive ratio is the proportion between the digestible protein (or nitrogenous material) and digestible carbohydrates to which is added a sum equal to 2.25 times the digestible fat. It has been held that a nutritive ratio of about 1 to 6 is especially favorable to the fattening of cattle. A ration consisting exclusively of cotton-seed meal and cotton-seed hulls usually contains a larger proportion of nitrogen, and hence has a narrower nutritive ratio than indicated above. Apparently the nutritive ratio was not a controlling factor in the rapidity of fattening.

TABLE 8.—*Nutritive ratio of rations fed.*

No. of pen.	1904–5	1905–6	1906–7	No. of pen.	1904–5	1905–6	1906–7
1	1:5.4	1:3.8	1:5	6	1:4.7	1:3.9	1:4.8
2	1:4.6	1:4.1	1:5	7	1:5.7	1:5.3	1:6
3	1:6.3	1:5.8	1:6.1	8	1:4.5	1:4.4	1:4.5
4	1:4.8	1:4.1	1:4.8	9	1:6.7	1:6.8	1:6.7
5	1:4.2	1:3.5	1:4.2	10	1:5.2	1:5.1	1:5.2

NOTES.—Ether extract multiplied by 2.25 to get its equivalent in carbohydrates.

Analyses and digestibility of all feeds except sorghum and stover taken from Henry's "Feeds and Feeding." Analyses of sorghum fodder and shredded stover made by C. L. Hare, of the Alabama Experiment Station.

Digestion coefficients of corn stover taken from Henry's tables, and for sorghum from Colorado Experiment Station Bulletin 93.

Average analyses of stover and sorghum for the years 1905–6 and 1906–7 (Hare).

	Dry matter.	Proteids.	Nitrogen-free extract.	Crude fiber.	Ether extract.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Stover	85.52	4.19	43.68	31.63	1.60
Sorghum	83.93	4.73	40.56	32.30	2.03

Digestion coefficients of sorghum and stover.

	Dry matter.	Proteids.	Nitrogen-free extract.	Crude fiber.	Ether extract.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Stover (Henry)	57.00	40.00	56.00	65.00	72.00
Sorghum (Colo. Station Bul. 93)	58.46	43.01	61.00	49.23	64.90

Digestible nutrients in corn stover:
4.19 × 0.40 = 1.68 per cent digestible protein in stover.

43.68 × .56 = 24.46 per cent digestible nitrogen-free extract.
31.63 × .65 = 20.56 per cent digestible crude fiber.

45.02 per cent total digestible carbohydrates.
1.60 × .72 = 1.15 per cent digestible fats.

Digestible nutrients in sorghum:
4.73 × 43.01 = 2.03 per cent digestible protein in sorghum.

40.56 × 61.00 = 24.74 per cent digestible nitrogen-free extract.
32.30 × 49.23 = 15.90 per cent digestible fiber.

40.64 per cent total digestible carbohydrates.
2.03 × 64.90 = 1.32 per cent digestible fats.

SLAUGHTER TESTS.

Through the courtesy of an abattoir company of New Orleans we were enabled to make slaughter tests of the steers butchered in New Orleans. A few of the steers were shipped out of the city to butchers in other places, and no data as to slaughter tests of such animals could be secured.

Dressed weight.—These figures are on the basis of the live weight in New Orleans. The average for three years shows that the scrubs dressed only 54.5 per cent as compared with an average of 57.2 per cent for the grades fed on the same ration. This means that in every 100 pounds gross weight there were 2.7 pounds more dressed meat in the carcasses of the grades than in those of the scrubs. The difference in selling price in New Orleans was 37 cents per hundredweight live weight in favor of the grades.

The table shows that the steers fed on cotton-seed meal and hulls dressed higher than those receiving any other ration, averaging 57.2 per cent. Next came the group of pens receiving hay with either corn or cotton seed as the principal concentrate, the hay pens falling about 1 per cent behind the hull pens. The pens receiving stover or sorghum made the poorest showing, falling about 1 per cent behind the hay pens, but dressing out better than the scrubs.

Fat on intestines and manyplies.—Not even the cotton-seed rations influenced very markedly the proportion of gut and book fat [a] to the live weight, the percentage of this kind of internal fat seeming to depend largely on the individuality of the steers.

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[a] Book fat is the term used in New Orleans abattoirs for the fat surrounding the manyplies, or third stomach.

TABLE 9.—*Percentage of dressed weight, fat, hide, blood, etc., on basis of live weight at New Orleans.*

No. of pen.	Dressed weight.				Gut and book fat.				Hide.		
	First year.	Second year.	Third year.	Average for three years.	First year.	Second year.	Third year.	Average for three periods.	First year.	Second year.	Third year.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1	[b]51.5	[a]54.5	56.9	54.5	[b]0.38	[a]1.28	[a]1.14	0.88	[b]8.0	[a]9.2	[a]7.7
2	[b]57.8	56.8	57.6	57.2	[b]2.2	1.18			8.2	7.5	
3	[b]56.3	57.2	58.3	57.3	[b]1.17	1.11			[b]8.1	7.6	
4	53.8	[b]56.4	56.6	55.4	1.14	[b]1.23	[b].95	1.03	8.1	[b]8.9	[b]7.8
5	53.6	[b]55.5	56.3	55.1	1.85	[a]1.19	[b]1.05	1.42	8.1	[a]8.3	[b]8.1
6	[b]56.2	[a]55.8	[b]59.3	57.2	[b]1.54	[a]1.22	[a]1.30	1.37	[b]7.7	[a]7.4	[a]7.6
7		[b]52.1	59.1				1.13				[b]8.3
8		[b]54.9	57.4			[b]1.14	[b]1.19			8.3	[b]8.2
9	[a]54.7	[b]54.6	57.8	56.0	[a]1.4	[a]1.26	[a]1.13	1.26	[a]8.6	[a]8.0	[a]8.0
10	[a]56.0	[a]57.5	57.1	56.9	[a]1.49		[b]1.10	1.27	[a]8.2		[a]7.9

No. of pen.	Blood.			Liver, lungs, heart, and diaphragm.			Paunch and intestines.		
	First year.	Second year.	Third year.	First year.	Second year.	Third year.	First year.	Second year.	Third year.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	2.8	2.41		2.8	3.0		[b]18.5	[a]18.87	15.6
2	[b]2.9	2.56		[b]2.7	2.8		13.2	16.7	
3	[b]2.5	[a]2.86	2.71	[b]2.8	[a]3.1	[a]2.9	[b]14.0	16.2	
4	2.5	[b]2.86	[b]3.28	2.9	[b]3.0	[b]2.8	15.9	[b]19.6	[b]16.5
5	2.6	[a]2.84	[b]2.70	3.0	[a]3.1	[b]2.6	13.3	[a]16.9	[b]16.7
6	[b]2.9	[a]2.83	[a]2.56	[b]2.9	[a]2.8	[a]2.8	[b]12.7	[a]15.33	[a]16.1
7			[b]2.96			[b]2.8	[a]16.5	[a]17.1	[a]17.7
8		[b]2.98	[b]3.00		[b]3.1	[b]2.6			[b]18.0
9	[a]2.6	[a]2.68	[a]2.75	[a]2.9	[a]2.9	[a]2.7		[b]17.6	[b]17.0
10	[a]2.6		[a]3.00	[a]3.0		[a]2.7	[a]15.1		[a]17.3

Unmarked pens have an average of 5 steers.

[a] Average of 3 steers. [b] Average of 4 steers.

SUMMARY.

The conclusions given below are based on the average of the three experiments.

1. With cotton-seed meal as the sole concentrate the average daily gains were as follows: With cotton-seed hulls, 1.55 pounds; with cut sorghum fodder, 1.39 pounds; with shredded corn stover, 1.19 pounds.

2. With mixed cowpea and sorghum hay as the roughage, and with one-third of the concentrate consisting of cotton-seed meal, the daily gain per steer from feeding cotton seed was 1.68 pounds, and from feeding an equal weight of corn-and-cob meal 1.71 pounds.

3. To produce 1 pound increase in live weight required practically equal amounts of cotton seed and of corn-and-cob meal. This shows that under the conditions of these experiments a pound of cotton seed was equally as valuable as a pound of corn-and-cob meal. Cotton seed is cheaper per pound, and hence is the more economical feed.

4. Cotton-seed meal proved more effective and economical than corn-and-cob meal when each was fed as an appetizer in connection with cotton seed.

5. When, in a ration of cotton-seed meal, one-third of the weight of the cotton-seed meal was substituted by an equal weight of corn-and-cob meal, the daily gains were slightly increased. The amount of concentrate per pound of gain was greater with the mixed ration, making this slightly less profitable than the ration containing cotton-seed meal as the sole concentrate.

6. The effect of shelter varied with the character of the winter. In two tests shelter increased the daily gains and decreased the amount of feed required per pound of gain. In the third experiment the pen fed without shelter made the larger gains and better use of its feed. The average of three years is in favor of shelter. The selling price in all three experiments was higher for the steers fed under shelter, the average difference being 13 cents per hundredweight in favor of the sheltered steers.

7. The scrub steers in two experiments made practically the same daily gains at practically the same cost as the grades. At the beginning of the other experiment the scrubs were thinner, and they gained more rapidly and economically.

8. Heavy shrinkage during shipment, due to unusual delays, greatly reduced the possible profits.

9. The average selling price of grades in New Orleans ranged between $3.97 (for the pen fed on corn stover, cotton-seed meal, and corn-and-cob meal) and $4.42 (for the pen fed on cotton-seed meal and hulls).

10. Of the eight rations fed the following were the most profitable at prices assumed: (1) Cotton-seed meal and hulls; (2) two-thirds cotton-seed meal, one-third corn-and-cob meal, with cotton-seed hulls as roughage. With cotton-seed meal at $20 a ton, hulls were worth in these experiments from $4.62 to $5.82 per ton. Inferior sorghum fodder and corn stover were worth less than hulls.

11. A margin ranging between 0.54 and 0.83 of a cent per pound in the feed lots for the different lots would have made the feeding operations come out even. To find the corresponding margin between purchase price and selling price in New Orleans, any intending shipper can add an amount sufficient to cover expenses of shipping and selling and shrinkage.

12. The scrubs dressed out 54.3 per cent as compared with 57.2 per cent for grades fed on a similar ration.

13. In percentage of dressed weight the best showing was made by the steers fed on cotton-seed meal and hulls, and the poorest by those fed on corn stover or on sorghum fodder. The steers receiving mixed hay ranked lower in percentage of dressed weight than those fed on hulls and higher than those fed on sorghum or corn stover.

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U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 104.

A. D. MELVIN, CHIEF OF BUREAU.

MEDICAL MILK COMMISSIONS AND THE PRODUCTION OF CERTIFIED MILK IN THE UNITED STATES.

BY

CLARENCE B. LANE,
Assistant Chief of the Dairy Division.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

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Renovated butter inspection.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., January 2, 1908.

Sir: I have the honor to transmit, and to recommend for publication as Bulletin 104 of this Bureau, the accompanying manuscript entitled "Medical Milk Commissions and the Production of Certified Milk in the United States," by Clarence B. Lane, assistant chief of the Dairy Division of this Bureau. The writer gives a history of the movement which has brought about the organization of milk commissions in a number of cities throughout the country, and describes the methods used in the production of what is termed "certified milk." The work of milk commissions and the production of certified milk not only result in supplying a high-grade product for special uses, but are believed to be important factors in improving the quality of the general milk supply.

Respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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MEDICAL MILK COMMISSIONS AND THE PRODUCTION OF CERTIFIED MILK IN THE UNITED STATES.

I.—THE WORK OF MILK COMMISSIONS.

The organization of milk commissions in this country was an important step toward the improvement of the quality of milk. While the number of commissions is very limited and the milk produced under their supervision amounts to only a fraction of 1 per cent of the 10,000,000,000 quarts or more of market milk annually consumed, the great value of certified milk to invalids and its influence in reducing the mortality among infants and children are beyond estimation. Further, the work of milk commissions has had no little influence in improving the general milk supply of cities where such commissions exist, by setting a higher standard of quality and by creating public sentiment in favor of pure milk.

THE FIRST COMMISSION: ITS ORGANIZATION AND OBJECTS.

The beginning of this movement dates back to 1890, when the Medical Society of New Jersey made an effort to improve the milk production in that State. A committee was appointed to make an investigation of the milk supply as far as it affected the public health. After two years' work this committee submitted a report condemning many of the methods employed in the production and handling of milk and advising an appeal to the State for a strict scientific supervision of all the dairies within its limits. The appeal was made, but failed. While the need was admitted, the authorities pleaded lack of funds for making the changes suggested.

This effort having met with defeat, another line of work was resorted to. The chairman, a Newark physician, presented a plan in 1892 to the Practitioners' Club of that city whereby physicians might themselves supervise the production of milk and thus be perfectly sure of its purity. The requirements for the production of certified milk were given with the utmost detail. It was recommended that a milk commission be formed by physicians who should certify to the milk over their names provided the requirements were fulfilled. This plan was indorsed by the Practitioners' Club, and a search was begun for a dairy with equipment suited to such rigid regulations. A dairy was found which had already set such a high standard that the methods used could readily be accommodated to the requirements of the medical commission.

Having secured a dairyman who was ready to bind himself by contract to conduct his dairy in accordance with the requirements, physicians from Newark, Orange, and Montclair were chosen to make up the first milk commission, which was organized April 13, 1893, and the production of what is known as "certified milk" was begun. This commission was named "The Medical Milk Commission of Essex County, New Jersey." Since this was organized about 25 others have been or are now being formed in various cities on a similar plan. A description of the first will therefore serve to give a general idea of milk commissions and their work.

OBJECTS OF THE COMMISSION.

The objects and requirements of the commission were stated as follows:

> The objects of this commission are to establish correct clinical standards of purity for cow's milk; to become responsible for a periodical inspection of the dairies under its patronage; provide for chemical and bacteriological examinations of the product, and the frequent scrutiny of the stock by competent veterinarians; to promote only professional and public interests.
>
> The following are three general requirements or standards for the milk: (1) An absence of large numbers of micro-organisms, and the entire freedom of the milk from pathogenic varieties; (2) unvarying resistance to early fermentative changes in the milk, so that it may be kept under ordinary conditions without extraordinary care; (3) a constant nutritive value of known chemical composition, and a uniform relation between the percentage of fats, proteids, and carbohydrates.

THREEFOLD EXAMINATION BY EXPERTS.

A chemist and a bacteriologist examine samples of the milk, which they obtain themselves, twice each month, and report their findings to the commission. A veterinarian examines the cows twice a month and makes report. Representatives of the commission in person make a monthly inspection of the dairy and report to the others.

The veterinarian must show the milch cows to be in perfect health. The chemist must show the milk to contain the required amount of solids and to be free from all foreign matter. The bacteriologist must show the absence of all disease-producing bacteria, and a minimum of bacteria of all sorts. Only in case all these reports are satisfactory does the commission certify to the milk.

ORIGIN AND MEANING OF THE TERM "CERTIFIED MILK."

The term "Certified Milk" originated with the member of the commission who formulated the plan. At the instance of the commission the word "Certified" was registered by Mr. Francisco in the United States Patent Office on October 16, 1904, under registery No. 25,368, the object being to protect it from being degraded by dairymen not under contract with a medical commission. It was distinctly understood, however, that the use of the term should be allowed without question when employed by medical milk commissions organized to influence dairy work for clinical purposes. Certified milk, then, in the strict sense of the term, is milk produced under a legal contract between a medical milk commission and a dairyman and which conforms to the requirements. It may be said further that milk entitled to be certified is clean and wholesome, and is obtained from healthy cows which are kept in sanitary quarters, fed wholesome feed, and given pure water. It is drawn from clean cows by clean, healthy attendants into clean receptacles and in a clean atmosphere. It is handled in a clean manner, cooled quickly, put into sterile vessels, placed in cold storage, and iced in transportation when necessary.

CONTROL OF DAIRIES.

Some commissions—particularly such as have under their supervision only one dairyman who both produces and distributes certified milk—enter into a binding contract with the dairymen. This contract contains a more or less complete and detailed statement of the conditions under which the certified milk must be produced and marketed; specifies standards for composition and bacterial content of the milk; provides for inspection of premises, examination of cows, and collection and analysis of milk samples; and includes provisions under which the contract may be terminated by either party entering into it.

Many commissions prefer not to have any contract with their producers and claim that it is superfluous and unnecessary. The producers understand well that if their milk does not come up to the requirements they can not sell it. However, in cases where there are contracts commissions are not at all hasty in severing relations with a producer when his milk falls below requirements, but make more frequent inspections and lend every effort at such inspections to help the dairyman out of his trouble. In this way, when a producer does have trouble he often writes to know when the commission can send a representative to help him out of his difficulty. The efforts of such commissions are therefore to help and cooperate closely with the producer. Some commissions feel safer in the work without a lengthy binding contract. This plan allows a certain latitude for meeting conditions as they arise, and the latter vary greatly at different farms even though the dairymen all produce milk well within the requirements and standards. Where there is no contract with the dairyman it is customary for the commissions to send a circular giving information concerning the production, standards, and general requirements of certified milk. A good example of such a circular follows:

REQUIREMENTS OF THE MILK COMMISSION OF THE MEDICAL SOCIETY OF THE COUNTY OF NEW YORK FOR CERTIFIED MILK.

* * * * * * *

The commission has fixed upon a maximum of 30,000 germs of all kinds per cubic centimeter of milk, which must not be exceeded to obtain the indorsement of the commission. This standard must be attained solely by measures directed toward scrupulous cleanliness, proper cooling, and prompt delivery.

The milk certified by the commission must contain not less than 4 per cent of butter-fat on the average, and have all other characteristics of pure, wholesome milk.

Milk must not be sold as certified more than twenty-four hours after its arrival in New York City.

Dealers.—In order that dealers who incur the expense and take the precautions necessary to furnish a truly clean and wholesome milk may have some suitable means of bringing these facts before the public, the commission offers them the right to use caps on their milk jars stamped with the words: "Certified by the Milk Commission of the Medical Society of the County of New York." The dealers are given the right to use these certificates when their milk is obtained under the conditions required by the commission and conforms to its standards.

In accordance with a law passed at the last legislature, the word "Certified" may be used on the cap only when accompanied by the name of the society which certifies it.

The tinned sealed cap authorized by the commission must be used on all the certified milk passing through the hands of dealers selling milk other than the certified. These caps are sent by the makers only to the farm where the milk is bottled.

The name of the farm from which the milk comes must appear on either the paper cap or the tin cap.

Each bottle of milk must be dated on the date of bottling.

The milk commission looks to the dealers for its fee.

The dealer is expected to send a bottle of milk each week to the research laboratory of the department of health, taken at random from the day's supply for examination by experts for the commission.

The dealers are to furnish deep, covered boxes for the certified milk.

The required conditions at the farm are as follows:

1. *The barnyard.*—The barnyard should be free from manure and well drained, so that it may not harbor stagnant water. The manure which collects each day should not be piled close to the barn, but should be taken several hundred feet away. If these rules are observed not only will the barnyard be free from objectionable smell, which is an injury to the milk, but the number of flies in summer will be considerably diminished. These flies are an element of danger, for they are fond of both filth and milk and are liable to get into the milk after having soiled their bodies and legs in recently visited filth, thus carrying it into the milk. Flies also irritate cows, and by making them nervous reduce the amount of their milk.

2. *The stable.*— In the stable the principles of cleanliness must be strictly observed. The room in which the cows are milked should have no storage loft above it; where this is not feasible the floor of the loft should be tight, to prevent the sifting of dust into the stable beneath.

The stables should be well ventilated, lighted, and drained, and should have tight floors, preferably of cement, never of dirt.

They should be whitewashed inside at least twice a year, unless the walls are painted or of smooth cement finish which can be washed frequently.

The air should always be fresh and without bad odor. A sufficient number of lanterns should be provided to enable the necessary work to be properly done during the dark hours. The manure should be removed twice daily, except when the cows are outside in the fields the entire time between the morning and afternoon milkings. The manure gutter must be kept in a sanitary condition. All sweeping must be finished before the grooming of the cows begins, so that the air may be free from dust at the time of milking.

There should be an adequate supply of warm and cold water, and the necessary wash basins, soap, and towels.

3. Water supply.—The whole premises used for dairy purposes, as well as the barn, must have a supply of water absolutely free from any danger of pollution with animal matter and sufficiently abundant for all purposes and easy of access.

4. The cows.—No cows will be allowed in the herd furnishing certified milk except those which have successfully passed a tuberculin test. All must be tested at least once a year, by a veterinarian approved by the milk commission. Any animal suspected of being in bad health must be promptly removed from the herd and her milk rejected. Do not allow the cows to be excited by hard driving, abuse, loud talking, or any unnecessary disturbance.

Feed.—Do not allow any strongly flavored food, like garlic, to be eaten by the cows. When ensilage is fed, it must be given in only one feeding daily, and that after the morning milking, and the full ration shall consist of not more than 20 pounds daily for the average-sized cow. When fed in the fall, small amounts must be given and the increase to the full ration must be gradual.

Corn stalks must not be fed until after the corn has blossomed, and the first feedings must be in small amounts and the increase must be gradual.

If fed otherwise, ensilage and corn stalks are liable to cause the milk to affect children seriously.

Cleaning.—Groom the entire body of the cow daily. Before each milking wash the udder with a cloth used only for the udders, and wipe it with a clean, dry towel. Never leave the udder wet, and be sure that the water and towel used are clean. The tail should be kept clean by frequent washing. If the hair on the flanks, tail, and udder is clipped close and the brush on the tail is cut short, it will be much easier to keep the cow clean.

The cows must be kept standing after the cleaning until the milking is finished. This may be done by a chain or a rope under the neck.

5. The milkers.—The milker must be personally clean. He should neither have nor come in contact with any contagious disease while employed in handling the milk. In case of any illness in the person or family of any employee in the dairy, such employee must absent himself from the dairy until a physician certifies that it is safe for him to return.

In order that the milk commission may be informed as to the health of the employees at the certified farms, the commission has had postal cards printed to be supplied to the farms, and to be filled out and returned each week by the owner, manager, or physician of the farm, certifying that none are handling the milk who are in contact with any contagious disease.

Before milking, the hands should be washed in warm water with soap and nail brush and well dried with a clean towel. On no account should the hands be wet during milking.

The milkers should have light-colored, washable suits, including caps, and not less than two clean suits weekly. The garments should be kept in a clean place, protected from dust, when not in use.

Iron milking stools are recommended, and they should be kept clean.

Milkers should do their work quietly and at the same hour morning and evening. Jerking the teat increases materially the bacterial contamination of the milk and should be forbidden.

6. Helpers other than milkers.—All persons engaged in the stable and dairy should be reliable and intelligent. Children under 12 should not be allowed in the stable or dairy during milking, since in their ignorance they may do harm, and from their liability to contagious diseases they are more apt than older persons to transmit them through the milk.

7. Small animals.—Cats and dogs must be excluded from the stables during the time of milking.

8. The milk.—All milk from cows sixty days before and ten days after calving must be rejected.

The first few streams from each teat should be discarded in order to free the milk ducts from the milk that has remained in them for some time and in which the bacteria are sure to have multiplied greatly. If any part of the milk is bloody or stringy or unnatural in appearance, the whole quantity yielded by that animal must be rejected. If any accident occurs in which a pail becomes dirty, or the milk in a pail becomes dirty, do not try to remove the dirt by straining, but put aside the pail, and do not use the milk for bottling, and use a clean pail.

Remove the milk from each cow from the stable immediately after it is obtained to a clean room and strain through a sterilized strainer of cheese cloth and absorbent cotton.

The rapid cooling is a matter of great importance. The milk should be cooled to 45° F. within an hour and not allowed to rise above that as long as it is in the hands of producer or dealer. In order to assist in the rapid cooling, the bottles should be cold before the milk is put into them.

Aeration of milk beyond that obtained in milking is unnecessary.

9. Utensils.—All utensils should be as simple in construction as possible, and so made that they may be thoroughly sterilized before each using.

Coolers, if used, should be sterilized in a closed sterilizer, unless a very high temperature can be obtained by the steam sent through them.

Bottling machines should be made entirely of metal with no rubber about them, and should be sterilized in the closed sterilizer before each milking, or bottling.

If cans are used, all should have smoothly soldered joints, with no places to collect the dirt.

Pails should have openings not exceeding 8 inches in diameter, and may be either straight pails, or the usual shape with the top protected by a hood.

Bottles should be of the kind known as "common sense," and capped with a sterilized paraffined paper disk, and the caps authorized by the commission.

All dairy utensils, including the bottles, must be thoroughly cleansed and sterilized. This can be done by first thoroughly rinsing in warm water, then washing with a brush and soap, or other alkaline cleansing material, and hot water, and thoroughly rinsing. After this cleansing they should be sterilized by boiling, or in a closed sterilizer with steam, and then kept inverted in a place free from dust.

10. The dairy.—The room or rooms where the utensils are washed and sterilized and the milk bottled should be at a distance from the house, so as to lessen the danger of transmitting through the milk any disease which may occur in the house.

The bottling room, where the milk is exposed, should be so situated that the doors may be entirely closed during the bottling and not opened to admit the milk nor to take out the filled bottles.

The empty cases should not be allowed to enter the bottling room nor should the washing of any utensils be allowed in the room.

The workers in the dairy should wear white washable suits, including cap, when handling the milk.

Bottles must be capped, as soon as possible after filling, with the sterilized disks.

11. *Examination of the milk, and dairy inspection.*—In order that the dealer and the commission may be kept informed of the character of the milk, specimens taken at random will be examined weekly by experts for the commission at the laboratory of the department of health, the use of the laboratories having been given for that purpose.

The commission reserves to itself the right to make inspections of certified farms at any time and to take specimens of the milk for examination and to impose fines for repeated or deliberate violations of the requirements of the commission.

The commission also reserves the right to change its standards in any reasonable manner upon due notice being given to the dealers.

The expenses of making the regular milk reports and the inspections are borne by the dealers. The treasurer of the Medical Society of the County of New York will send bills the first of each month for the certification for the previous month.

The monthly charges, which are intended to cover all expenses, are as follows:

Where the output of a farm is handled by one dealer:

For daily output of less than 100 quarts	$8
For daily output of from 100 to 200 quarts	10
For daily output of from 200 to 500 quarts	12
For daily output of over 500 quarts	15

Where the output of a farm is sent to several dealers, each dealer pays:

For daily output of less than 100 quarts	6
For daily output of from 100 to 200 quarts	8
For daily output of from 200 to 500 quarts	10
For daily output of over 500 quarts	12

The names of the dealers, with their addresses, are printed on cards and inclosed with the monthly bulletin of the medical society, which is sent to about 1,700 physicians. For this $1 is charged each month.

FORM FOR DAIRYMAN'S APPLICATION FOR CERTIFICATION OF MILK AND CREAM.

Application of dairyman.

Date........................190....

I hereby make application to the Jackson County Medical Society for the certification of milk and cream to be sold by me in the city of Jackson. In consideration of such certification I agree to observe such rules and regulations as may from time to time be enacted by the committee appointed by the Jackson County Medical Society. I also agree to allow such committee or their proper representatives, whenever they request it, to remove from any milk wagon or from the dairy a reasonable sample of milk or cream. It is understood that failure to comply with the rules of the committee will result in the suspension or withdrawal of my certification.

Name of dairy..
License No............ Residence..
Name of former owner..
Number of quarts of milk and cream per day.................................
If obtained from outside sources other than dairy owned by applicant, give names and addresses..

Signature of applicant........................ ..

To Dr..Secretary,
Colony Building, Jackson, Mich.

FORM FOR MILK COMMISSION'S CERTIFICATE TO THE DAIRYMAN.

The Milk Commission of the Academy of Medicine, Cincinnati, Ohio.

Date..................................

The veterinary inspector of the commission has examined the dairy of Mr.......................................and reports it to be well kept and clean, and the cows to be in healthy condition.

The bacteriologist reports that the milk does not contain germs beyond the limits of the standards of the commission for..................................milk.

The chemist reports that the milk is of standard richness, and that he has discovered in it no impurities, coloring matters, chemical preservatives, or harmful substances.

The commission certifies to these statements of examiners. It is understood and agreed to by the said..
that this certificate is not good for more than...
from date, before which time another examination will be made.

Signed................................

METHODS AND WORK OF THE VARIOUS MILK COMMISSIONS.

As previously stated, the first milk commission was organized April 13, 1893, and it was not until five years later (1898) that the second was formed. After 1899 the movement spread more rapidly and commissions were organized as follows: One in 1900, one in 1901, five in 1902, two in 1903, three in 1904, one in 1905, five in 1906, and thirteen organized or in process of organizing in 1907. The subject is being agitated in several cities at the present time and it is quite probable that the number of commissions will be considerably increased in the near future. In order to obtain information relative to the work of the commissions and their methods of operation a list of queries was sent to each. The answers received from the commissions have been summarized in Table 1, page 15.

TABLE 1.—*Facts relating to the work of milk commissions.*[a]

Name of commission.	When organized.	Standards established.			Difficulty in keeping milk up to standard.	Number of dairies.	Milk handled daily.	Price per quart of certified milk.	Price per quart of ordinary market milk.
		Maximum bacteria per cubic centimeter.	Butter fat.	Solids not fat.					
			Per cent.	*Per cent.*			*Quarts.*	*Cents.*	*Cents.*
Essex County (N. J.) Medical Milk Commission	1893	(b)	4.5	9.0	No.	1	2,500	12	8
Milk Commission of Hartford County Medical Society, Hartford, Conn.[c]	1898								
Philadelphia Pediatric Society Milk Commission	1899	10,000	[d] 3.5-5.5	(b)	No.	4	2,450	12-16	8-10
Milk Commission of the Medical Society of the County of New York (N. Y.)	1900	30,000	4.0	(b)	Little.	20	9,373	12-20	8
Milk Commission of the Rochester (N. Y.) Academy of Science	1901	10,000	3.5	9.0	Little.	1	230	10	6
Milk Commission of the Medical Society of the County of Kings (N. Y.)	1902	[e] 20,000 10,000	4.0	(b)	Some.	8	2,810	12	6-8
Milk Commission of the Elmira (N. Y.) Academy of Science	1902	10,000	3.5-4.5	(f)	No.	1	120	8	5
Milk Commission of the Medical Society of the County of Albany (N. Y.)	1902	[e] 10,000 5,000	3.5-4.5		No.	1	225	12	6
Medical Society of the District of Columbia Milk Commission[c]	1902								
Milk Commission of the Hennepin County Medical Society (Minneapolis Minn.)	1902	10,000	3.5-4.5	8.5	No.			10	6
Milk Commission of the Milwaukee Medical Society	1903	10,000	3.75-4.5	8.0	No.	1	2,000	12	6
Milk Commission of the Children's Hospital of Chicago	1903	30,000	4.0	(b)		1	300	[g] 12	6
The St. Louis Pure-Milk Commission	1904	30,000	3.25-4.5	8.6	No.	2	336	15	7-8½
Milk Commission of the City of Cleveland	1904	10,000	4.0	(b)	Little.	1	447	15	7
Oakland (Cal.) Home Club Milk Commission	1904	10,000	4.0	8.0	No.	1	600	12½	9
Milk Commission of Syracuse Academy of Medicine, Syracuse, N. Y.[c]	1905								
Milk Commission of the San Francisco County (Cal.) Medical Society	1906	20,000	3.5	(b)	No.	(h)	(h)	12½-13	10
Milk Commission of the Academy of Medicine (Cincinnati, Ohio)	1906	10,000	4.0	(b)	No.	1	400	14	6
Milk Commission of the Cambridge (Mass.) Medical Improvement Society	1906	10,000	3.7	9.3	Little.	1	750	10	7-8
Jefferson County Medical Society Milk Commission (Louisville, Ky.)	1906	10,000	4.0	8.0	Little.	3	632	10	7½
Commission of the Suffolk District Medical Society (Boston, Mass)	1906	10,000	3.5-4.5	(b)	Little.		250	20	8-10
Milk Commission of the Academy of Medicine of Toledo (Ohio)	1907	10,000	4.0			1		12	6-8
Jackson County Medical Society Milk Commission (Jackson, Mich.)	1907	[e] 50,000 25,000	3.5		No.	2	430	8	7
Montgomery County Medical Milk Commission, Dayton, Ohio	1907	10,000	4.5		No.	1	250	12	7-9
Wayne County Medical Milk Commission, Detroit, Mich	(i)								
Summit County Medical Milk Commission, Akron, Ohio	(i)								
Kansas City Pure Milk Commission, Kansas City, Kans	(i)								
Rutland County Medical Milk Commission, Rutland, Vt	(i)								

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[a] Data largely collected prior to January 1, 1907. Milk commissions are also in process of formation at New Orleans, La.; Pittsburg, Pa.; Jacksonville, Fla.; Colorado Springs, Colo.; Binghamton, N. Y., and Bethlehem, Pa.

[b] No standard established.

[c] Not active at the present time—1908.

[d] Milk sold as 4 per cent milk is allowed to vary from 3.5 to 4.5 per cent. That sold as 5 per cent milk is allowed to vary from 4.5 to 5.5 per cent.

[e] Higher limit for summer; lower for winter.

[f] Specific gravity 1.029 to 1.034; proteid 3.5 to 4.5; sugar 4 to 5 per cent.

[g] Sold for infant feeding at about half this price.

[h] Operations suspended at time of report owing to effects of earthquake and fire.

[i] Now organizing.

NUMBER OF CERTIFIED DAIRIES AND QUANTITY OF MILK PRODUCED.

The number of dairies producing milk for any one commission varies from 1 to 20. Eleven commissions have 1 each; three have 2; one has 3; one 4; and one 20. Four commissions have temporarily stopped certifying to milk, namely, Hartford, Minneapolis, San Francisco, and Washington. The least amount handled daily by any one commission is 120 quarts and the greatest amount 9,373 quarts. (See Table 1.) A few commissions certify to cream as well as milk. The reports from commissions show that there were 24,103 quarts of certified milk handled daily on January 1, 1907.

STANDARDS FOR CONDITION AND QUALITY OF MILK.

The standards for bacteria vary with the different commissions. Of the 20 reporting standards, 13 place the number at 10,000 per cubic centimeter, 1 at 20,000, and 3 at 30,000. One has a standard of 10,000 from October to April, and 20,000 from April to October. Another has a standard of 5,000 in winter and 10,000 in summer, and another a standard of 25,000 in winter and 50,000 in summer. The standard for cream in all cases where it is certified is 25,000 per cubic centimeter.

The standard required for fat in eight instances is a minimum of 4 per cent; in three instances, 3.5; in two, 4.5; and in one, 3.7+. Four allow a range of 3.5 to 4.5, one a range of 3.25 to 4.50, and one 3.75 to 4.50. One puts out a special milk containing a higher percentage of fat, which must keep within the limits of 4.50 and 5.50 per cent. One commission specifies that the cream must not vary more than 2 per cent from the guaranty. Only eight commissions report standards for solids not fat. These range from 8 to 9.3 per cent.

LIVING UP TO THE STANDARD.

Twelve commissions report that their dairies have no difficulty in producing milk that is up to the required standards. Five report a little difficulty, and one states that there was no trouble with the bacteria count, but that it took several months to reach the fat standard, which was 4 per cent.

INSPECTION OF DAIRY AND PRODUCT.

The answers from the various commissions relative to inspections show considerable variation. In some instances the inspections are made by members of the commission and in others paid inspectors are employed to do the work. As a rule inspections of the dairy are made monthly either by a veterinarian or a member of the commission, or both, and in some instances inspections are made every two weeks. The tuberculin test is usually applied annually, but in some cases this is done every six months. Chemical and bacteriological examinations range all the way from once a week to once in two months; in most instances, however, it is the practice to make tests every two weeks or oftener.

HEALTH OF EMPLOYEES.

The employees in certified-milk plants are required to be clean in habits and appearance and are not admitted to the stables or dairy if not in good health. Some commissions require that employees be regularly examined by a physician and given certificates of health. In some certified plants attendants when ill are cared for in a building specially set apart for the purpose.

PRECAUTIONS TO PREVENT SPREAD OF CONTAGIOUS DISEASES.

Where a large milk business is conducted and several thousand customers are served daily, there is danger that some contagious disease may be brought to the dairy in some of the bottles. To avoid this, in some instances a wagon makes a special trip to collect bottles from any house where a contagious disease is known to exist. These bottles are thoroughly boiled in a special room before they come to the dairy proper. They are then subjected to the same cleansing process as all the others.

INVESTIGATIONS RELATIVE TO QUALITY OF CERTIFIED MILK.

Milk commissions have sometimes been criticised for not being strict enough with the dairymen in regard to complying with their standards. Reports from the commissions show that in nearly all cases samples are secured from the distributor without warning, which is a very important and commendable practice, for if the milk, when it reaches the consumer, does not comply with the standards which the commission claims to maintain, the product is misrepresented and is a fraud.

In order to determine this point an investigation was made in two of the larger cities where certified milk is sold.

First investigation.—The standard for bacteria of the milk commission in the city where this investigation was made was 10,000 per cubic centimeter. There were four certified dairies supplying milk, and the bacteria count was as follows:

	Bacteria per cubic centimeter.		Bacteria per cubic centimeter.
Dairy No. 1	5,700	Dairy No. 3	5,600
Dairy No. 2	4,200	Dairy No. 4	4,900

It will be seen that the certified milk from all four of the dairies was well within the limits of the standard established by the commission. The analyses were made in the month of November.

Second investigation.—The standard for bacteria established by the commission in this city was 30,000. Nine samples of certified milk were examined with the following results:

	Bacteria per cubic centimeter.		Bacteria per cubic centimeter.
No. 1	9,300	No. 6	11,000
No. 2	2,300	No. 7	6,200
No. 3	21,300	No. 8	5,400
No. 4	13,700	No. 9	2,700
No. 5	12,800		

All of the above samples were well under the standard of 30,000, the highest being 21,300 and the lowest 2,300.

While the bacteria count in these samples is doubtless somewhat lower than would be found under summer conditions, still it is an indication that the commissions are doing careful, honest work.

The reports of commissions indicated that the milk from the various certified dairies follows the standards very closely in composition. Some reported very careful records of examinations for bacteria. As a rule the number of bacteria found was considerably below the number allowed. The Rochester commission reported the average of 100 examinations to be 3,853 per cubic centimeter. The Cleveland commission reported an average of 3,817 for one year, and the Elmira commission 3,500 for the same period. The percentage of fat in the milk reported shows a variation from 3.80 to 5.40 and an average for all certified milk of 4.54 per cent.

SOME GENERAL CONSIDERATIONS.

IS THE DEMAND FOR CERTIFIED MILK INCREASING?

All but one of the commissions reporting stated that the demand for certified milk was increasing. One stated that the demand had doubled in one year and another that it had nearly trebled in two months. New commissions are constantly being organized, and it appears that there is no lack of demand for the product in most instances; but, on the other hand, there is a scarcity of dairymen who are willing to meet the requirements for production imposed by the commissions.

PRICES OF CERTIFIED MILK COMPARED WITH THOSE OF MARKET MILK.

The prices of certified milk to the consumer vary in different cities from 8 cents to 20 cents a quart, the average price for all cities being about 12½ cents. The price of ordinary market milk varies from 5 cents to 10 cents a quart and averages about 7½ cents. Certified milk therefore sells for an average of 5 cents more per quart than market milk. As a rule, where the price of market milk is low, the price of certified milk is also comparatively low, although this does not hold true in all cases. In some cities different prices are charged for certified milk; for example, in New York this product sells at prices varying from 12 cents to 20 cents, while the price of market milk is generally 8 cents per quart.

INFLUENCE OF MILK COMMISSIONS ON THE QUALITY OF THE GENERAL SUPPLY.

Fourteen of the eighteen commissions reporting on this question stated that they believed the commissions had had some influence in improving the general supply; two others stated that they were trying to effect some improvements; one stated that perhaps some influence was exerted, and the remaining one did not venture an opinion. These improvements have been brought about through the influence of the commissions in securing better regulations and higher standards relative to producing and handling milk; in modifying advertisements which misrepresented some of the milk sold in the city; in interesting local papers in clean-milk movements, and in assisting in making prosecutions.

The producers of certified milk also have a good influence upon the general milk supply by setting examples of cleanliness and good management. Milk venders in the city by displaying signs on their wagons showing that their milk has been approved by a commission appointed for this purpose have had a good effect upon the market-milk trade. Market-milk producers are encouraged to make improvements and in time become certified-milk producers, better prices for their product being the principal inducement.

SO-CALLED CERTIFIED MILK NOT CONTROLLED BY MILK COMMISSIONS.

There are a few dairymen who sell their product under the name of certified milk who have no connection with milk commissions. These in some cases certify to their own product, and in others samples are sent to a State experiment station or to some local chemist or bacteriologist for examination. Some dairymen in this class supply a very creditable product. There are others whose milk is of only ordinary quality and who should never be allowed to use the term "certified." Here again the samples for analysis are usually taken by the dairyman himself from milk fresh from the cow and immediately iced and sent to the analyst. The analyst reports his results and the dairyman uses them to advertise his product. This can not be looked upon as anything but a deception, as the consumer is given to understand that this is the analysis of the milk as it is delivered to him daily. It is only when medical milk commissions have been organized and a plan of education has been started to create a demand for sanitary milk designed for infant feeding that there arises any danger of an impure milk being put on the market under such a label. It is manifestly unfair, therefore, that, after a commission, serving without pay in the interest of the public, has created a feeling that "certified" milk means a safe, clean milk for infant feeding, some unprincipled dairyman should be able to prey on the ignorance of the public and supply an unsafe milk at a high price. Some steps should be taken by the milk commissions or by city or State officers to prevent such practices. Where milk is an article of interstate commerce, however, the national pure-food law covers misrepresentations of this character.

LEGALIZATION OF THE TERM "CERTIFIED MILK."

The State of New York has set a good example in recently passing a law for regulating the sale of certified milk. A portion of the law reads as follows:

> No person shall sell or exchange, or offer or expose for sale or exchange, as and for certified milk any milk which does not conform to the regulations prescribed by, and bear the certification of, a milk commission appointed by a county medical society organized under and chartered by the Medical Society of the State of New York and which has not been pronounced by such authority to be free from antiseptics, added preservatives, and pathogenic bacteria, or bacteria in excessive numbers. All milk sold as certified milk shall be conspicuously marked with the name of the commission certifying it.

Efforts are being made to secure the passage of similar legislation in several other States, and there is every indication that misusers of the term "certified" will be prosecuted in the future.[a]

FINANCIAL SUPPORT OF MILK COMMISSIONS.

Members of milk commissions rarely receive any pay for their work, their services being given gratis for the public good. Small expenses of the commission are usually met by the commission itself. Occasionally philanthropic subscriptions are received. In one city three men contributed $800 after an appeal by the commission. Postage, printing, and salaries of experts are usually paid by the producers. There are several methods used for collecting the money from dairymen to meet these expenses, the most common one being the sale of caps to milk producers at from $4.75 to $5 a thousand. One commission charges a tax of half a cent a quart for certification. Another commission meets its incidental expenses by charging each dairyman $6 a month. The most successful and just method is apparently that of a "per bottle tax."

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[a] The Kentucky legislature on February 12, 1908, passed a pure-food law containing provisions regarding certified milk.

THE AMERICAN ASSOCIATION OF MEDICAL MILK COMMISSIONS.[a]

When it is considered how very efficient milk commissions have been in the various communities in which they have been established, it is surprising how few have been formed since the first one was organized in 1893. The spread of this movement was undoubtedly retarded because of the difficulties that presented themselves to those who had such an organization in contemplation. The question was not broadly understood by the medical profession, and even when the organization of a milk commission was determined upon it was difficult to arrive at the most acceptable plan of organization and detail of working methods.

The usual procedure was to get into correspondence with one of the older commissions, which would relate its individual way of handling this problem. If the plan submitted seemed unsatisfactory, other commissions would be written to, and so an endless correspondence resulted, which proved especially burdensome to the Newark, N. J., commission.

The secretary of the Cincinnati commission, Dr. Otto P. Geier, encountered this same difficulty at the period of organization of that commission. It resulted in his sending out a series of 24 questions covering every phase of activity in milk-commission work. These were addressed to every commission then known. This very exhaustive tabulation showed that there existed considerable lack of uniformity as to organization, working methods, supervision of dairies, chemical and bacteriological standards, methods of bottling, capping and sealing, etc.

Out of this mass of correspondence an attempt was made to arrive at the most acceptable standards and working factors, and the conclusion was reached that a conference of the milk commissions would be most valuable to all concerned.

In February, 1907, the Cincinnati commission addressed the various milk commissions suggesting a conference to be held in connection with the meeting of the American Medical Association at Atlantic City. Out of this grew a temporary organization. Dr. Henry L. Coit, Dr. Otto P. Geier, Dr. Samuel McC. Hamill, Dr. Rowland G. Freeman, Dr. William H. Park, and Dr. Thomas W. Harvey, acting as a committee, formulated a program and called the conference for June 3, 1907, at Atlantic City.

This initial conference was remarkable in that delegates were present from 12 different States, representing 21 commissions in as many cities. Over 100 physicians and leading hygienists attended this meeting, and a tremendous amount of work was accomplished.

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[a] The writer is indebted to Dr. Otto P. Geier, secretary of the American Association of Medical Milk Commissions, for data regarding the organization of the association.

Reports were read by delegates as to the work of their particular commissions. Papers were presented on the broad topic of a pure-milk supply for cities. A permanent organization was effected, to be known as the American Association of Medical Milk Commissions, and the following officers were elected:

President, Dr. Henry L. Coit.
Secretary, Dr. Otto P. Geier.
Treasurer, Dr. Samuel McC. Hamill.
Council: Dr. Rowland G. Freeman, chairman (5 years), Dr. Henry Enos Tuley (4 years), Dr. C. W. Brown (3 years), Dr. A. W. Myers (2 years), Dr. H. L. K. Shaw (1 year), and the president, secretary, and treasurer of the association.

Committees were appointed upon every phase of activity in milk certification to investigate and report at the next annual meeting.

It can be said that this meeting marks a new era in the pure-milk crusade. It is agreed that this organization is in position to crystallize the best thought that has been given to this subject, and that through such central organization quick dissemination of that knowledge will follow.

A better understanding of this subject will reveal the fact that milk commissions are widening their scope and that through their activity the quality of the general supply of milk in our large cities is being elevated. It will show that it is practical for any medical association to form such a commission, which, once formed, will be most useful in educating the public as well as the profession and in creating a demand for a cleaner milk supply, and will thus further the efforts of boards of health.

The necessity for such an organization is shown by the records of its secretary, who has been in correspondence with 11 commissions organized since June, 1907, indicating an increase of 50 per cent over the number of commissions then known to exist.

The second annual meeting will be held in Chicago June 1, 1908, one day previous to the meeting of the American Medical Association.

II.—THE PRODUCTION OF CERTIFIED MILK.

INFORMATION SECURED FROM PRODUCERS.

In order to secure accurate data relative to the production of certified milk a list of questions was sent to dairymen producing this grade of milk, and the information given is briefly shown in Table 2.

It will be seen from the table that 33 of the 50 dairies producing certified milk in the United States reported in response to queries sent them. Their answers give us sufficient data for a description of the methods commonly practiced in certified-milk production.

Plates I and II show the exterior and interior views of several stables used in the production of certified milk, and Plates III and IV the methods of handling the cows and the milk.

NUMBER AND BREED OF COWS AND QUANTITY AND QUALITY OF MILK.

The number of cows in herds producing certified milk varies from 25 to 500. Practically every breed is represented in some of these herds, and some grade or native stock is found in two-thirds of them. There are several herds of registered animals. The breed is not considered of special importance with most of the commissions, provided the composition of the milk produced is within the limits of the standard prescribed. The health of the animals and cleanliness of the surroundings and product are the most important elements in production. The production of the different herds ranges from 225 to 5,000 quarts daily (though the milk from the largest herd is not all certified). The butterfat in the milk as reported varies from 3.6 to 6.5 per cent and averages about 4.69 per cent. This agrees fairly well with the average percentage of 4.54 reported by the commissions, the difference probably being due to the fact that only 33 dairies are represented in the average for dairies while the average reported by commissions represents practically all the certified-milk producers.

BACTERIA IN THE MILK.

The number of bacteria in the milk, as reported by the dairymen, varies all the way from 200 to 10,000 per cubic centimeter. One (No. 11) has an average of 3,317 for 43 weeks; another (No. 29) reports a count of below 1,000 for one year and an average of 150 for 15 successive weeks from samples taken at random in the city.

METHODS OF CLEANING AND DISINFECTING STABLES.

It is the general practice in certified dairies to remove the manure at least twice daily to the field, or to a suitable pit some distance from the stable. In the most carefully managed dairies the whole interior of the stable is washed and scrubbed daily with water con-

No. of dairy.	Location.	No. of cows in herd.	Milk produced daily.[a]	Breed of cows.	Average quality and condition of milk.		Temperature of milk.		Is production of certified milk profitable?	Price per quart of certified milk.
					Fat in milk.	Bacteria.	Cooled.	Stored.		
			Quarts.		*Per cent.*	*Per c. c.*	° *F.*	° *F.*		*Cents.*
1	East Schodack, N. Y.	25	225	Jerseys, Holsteins, and grades	4.6	3,350	42	42	Fairly so	[b] 5–5½
2	Wawa, Pa.	150	1,300	Guernseys, grades, and natives	4.7	2,000–5,000	40	40	Yes	[c] 14–16
3	Barrytown, N. Y.	34	200	Jersey and Guernsey grades	5.0	1,500	35	40	Yes	[b] 7
4	Warwick, N. Y.	52	540	Mixed breeding	4.0	800–1,000	45–48	50	Yes	
5	Warwick, N. Y.	65	650	Durhams	4.0	1,060–2,000	38–40	38–40	Think so	
6	Willow Grove, Pa.	40	250	Jerseys (purebred and grades)	4.75	8,000	48	48	Yes	[b] 8½
7	Norwich, N. Y.	40	350	Guernseys, Jerseys, and Holsteins	4.5	500–5,000	45–50	45–50	Yes	[b] 6
8	Smithboro, N. Y.	60	600	Holsteins and Jerseys	4.3	1,000			Fairly so	[b] 6
9	Malvern, Pa.	70	600	Mixed breeds	4.0	4,000	36–40	36–40	No	[b] 7½; [c] 14
10	Oakland, Cal.	100	750	Mixed breeds	4.0	500–7,000	50–60	50–60		12
11	Dover Plains, N. Y.	56	550	No special breed	4.35	[d] 3,317	40–45	40–45	No	[b] 6
12	Kinderhook, N. Y.	50	250	Registered Jerseys	5.9	[e] 9,681	36–40	36–40	Yes	
13	Waltham, Mass.	88	900	Mixed breeds	4.1	6,500	50	40	Just begun	10
14	Highland, N. Y.	39	150	Jerseys	5.6	100–500	36–40	36–40	No	10
15	Haddonsfield, N. J.	75	450	Registered Guernseys	5.0	Under 4,000	40–50	40–50	No	
16	Earlville, N. Y.	55	300	Jerseys and natives	4.5	2,800	37	37	No	[b] 6
17	Walden, N. Y.	75	500	Jerseys, Guernseys and Natives	4.5	5,000	40–45	40	Yes	12
18	West Vienna, N. Y.	103	500	Grade Jerseys, Guernseys, etc.	5.0	900	40	40	Just begun	[b] 6–7
19	Greenwood, Mo.	65	720	Purebred Holsteins	3.6	8,000	48	48	Yes, at 15 cts.	10; [f] 15
20	Selma, Mo.	70	560	Jerseys and Holsteins (purebred and grades)	4.7	3,500	45	45	Yes	
21	Tully, N. Y.	275	1,900	Jersey, Holstein and Swiss grades	4.5	500–1,000	36–40	36–40	Will be	12
22	White Plains, N. Y.	40	360	Jerseys	6.0	600	32–38	32–38	Yes	15
23	Kingsleys, Pa.	32	265	Jerseys	5.4	400			No	
24	New Roadhouse, Ill.	30	75	Grade Holsteins	4.8	6,000	40–50	40–50		[b] 9
25	Lebanon, Ohio	66	475	Shorthorns and mixed	4.0	2,000	45	45	Yes	14
26	Briarcliff Manor, N.Y.	300	2,853	Jerseys (purebred and grade)	5.65	6,320	38–45	38–45	Yes	[g] 10–20
27	Rochester, N. Y.	50	334	Jerseys and mixed blood	4.1	4,000	45–50	45–50		10
28	Pewaukee, Wis.	350	2,200	Holstein, Guernsey, and Jersey grades	4.0	2,000	38	50		12
29	Newburgh, N. Y.	100	600	Jersey and Guernsey grades	5.0	Under 1,000	40	38		[h] 20
30	Canajoharie, N. Y.	40	225	Holsteins and Jerseys	4.0	1,500–5,000	40–50	40–50	Yes	12
31	Anchorage, Ky.	21	200	Jerseys	6.5	3,000	45		Yes	[c] 10
32	Fairfield, N. J.	517	5,000	Mixed breeding	4.5	Under 10,000	39	40	Yes	[c] 12
33	Cedarhurst, N. Y.	52	600	Guernsey grades	5.0	200–3,500	42	42–45	Yes, if large	[i] 10

[a] Approximate.

[b] Wholesale.

[c] Retail.

[d] Average for forty-three weeks.

[e] Average for six months.

[f] For table use, 10 cents; for infant feeding, 15 cents.

[g] In home market, 10 cents; in New York City, 20 cents.

[h] In New York City.

[i] At farm.

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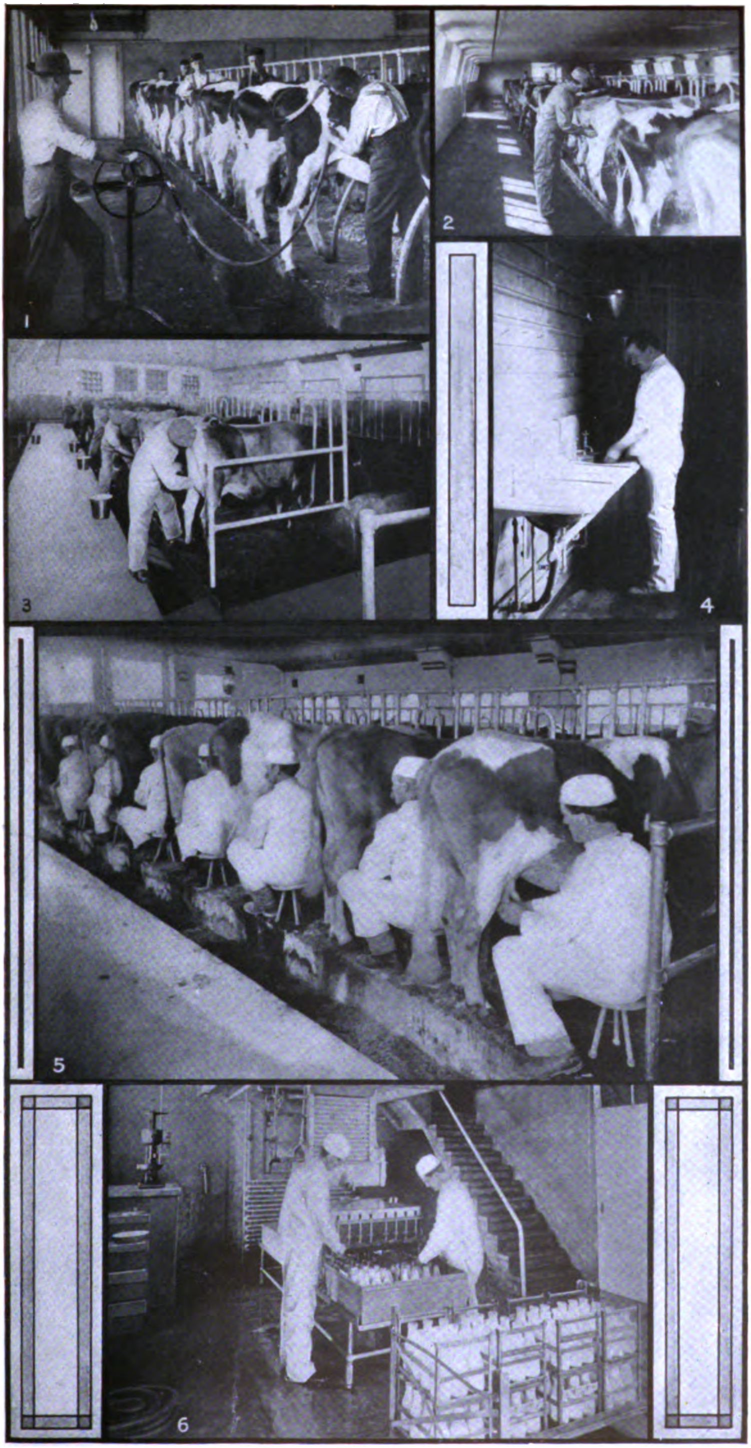
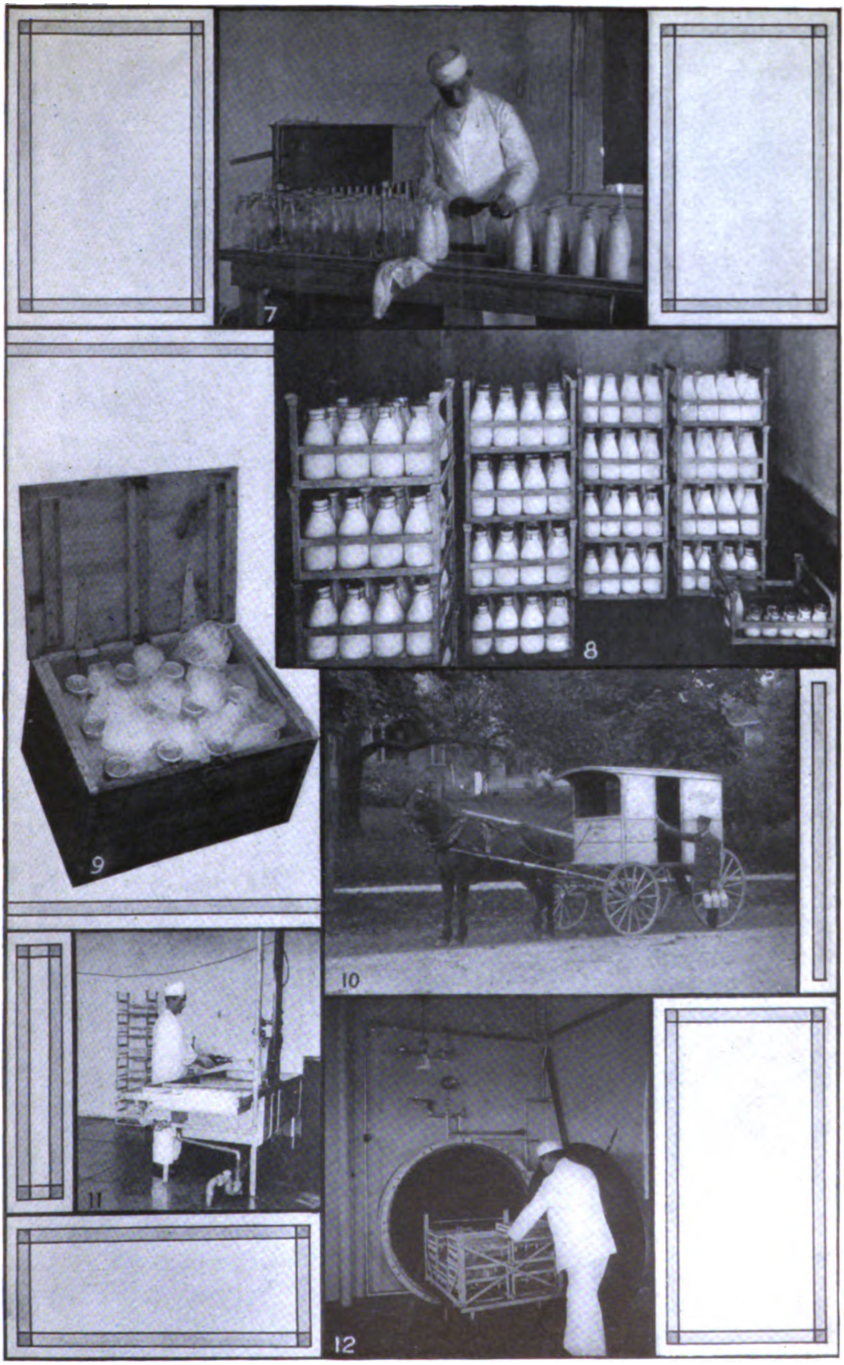
EXTERIOR VIEWS OF DAIRY STABLES WHERE CERTIFIED MILK IS PRODUCED.

PLATE III.



STEPS IN THE PRODUCTION AND HANDLING OF CERTIFIED MILK.

1. Clipping cows. 2. Cleaning cows. 3. Washing cows preparatory to milking. 4. Milker washing hands. 5. Milking. 6. Cooling and bottling.



STEPS IN THE HANDLING AND DELIVERY OF CERTIFIED MILK.

7. Sealing bottles. 8. Storage. 9. Case of bottles ready for delivery. 10. Delivery wagon. 11. Washing bottles. 12. Sterilizing bottles.

taining a washing compound. Some use a disinfectant in the water once or twice a week, as bichlorid of mercury, carbolic acid, or permanganate of potash. Bichlorid of mercury is probably the most expensive of any of the disinfectants; aside from this fact it is one of the most satisfactory because it gives off no odor. One dairyman uses cresol in water daily. Where the interior of the stable is built of wood, it is whitewashed from two to twelve times annually, or kept well painted. Land plaster is the most common disinfectant for floors and gutters. Slacked lime is also satisfactory for this purpose. Shavings are most in favor for bedding. Some dairymen do not use any bedding, but this system is not recommended.

CLEANING AND TREATMENT OF COWS PREPARATORY TO MILKING.

The cows are cleaned daily with currycomb and brush. (Pl. III, 2.) The udder and parts in proximity to it are either washed and wiped with a clean towel, or are wiped with a damp cloth or sponge. (Pl. III, 3.) In many cases the udder, flanks, etc., are clipped periodically. (Pl. III, 1.) Occasionally a dairyman sprays stables and cows immediately before milking. It is a common practice to fasten up the cows after they have been cleaned, in such a way that they can not lie down till they have been milked.

In a few dairies where extraordinary care is used, the whole body of the cow is groomed an hour or more before each milking, and any soiled parts are scrubbed with a brush and water containing a washing compound; the entire body is bathed from the neck back; the tail is washed; the udder is washed in sterile water from a sterile pail, and dried with a clean towel, a separate one being provided for each cow.

MILKERS AND MILKING.

In a few dairies the milking is not done in the regular stable, the cows being taken to a milking room entirely separated from the rest of the barn. This room is well lighted, and every precaution is taken to make it absolutely sanitary. Other dairymen claim that just as good results can be secured by milking in the regular stable if proper precautions are taken. As some of the lowest bacteria counts on record have been obtained where the latter plan is followed, this fact would seem to substantiate the claim.

The custom is almost universal for the milkers to be clad in freshly laundered suits. Where the most extreme care is taken, the clothing of each milker receives a thorough cleansing with boiling water after every milking, and is then locked in an individual air-tight drying room, where it is sterilized and dried by steam, remaining there until wanted for use. Before putting on their special suits, milkers are required to wash their hands and faces and clean their nails. (Pl. III, 4.) At least one producer requires that before the milker commences his work he shall take a shower bath, provision for which is made in rooms adjoining the laundry. When ready for milking the milker is supplied with a pail and a stool, both of which have been cleansed and sterilized since last in use. With these extreme precautions, when the milker goes to the milk room, he is as clean in person and equipment as it is possible to make him. (Pl. III, 5.) In milking it is a common practice to discard the foremilk. The milking is done strictly with dry hands, except in a few instances where vaseline is employed (a usage which is reported to be entirely practical). In some dairies milkers are required to wash their hands before milking each cow, but this is not the general practice.

HANDLING THE MILK.

After being drawn the milk is taken immediately to a separate room, where it is strained into a can through a double thickness of cheese cloth (a separate strainer being used for each pail of milk). It is then taken immediately to the bottling room (Pl. III, 6), where usually it is cooled to a temperature as low as 45° to 50° F., and in some cases as low as 35° F. Sometimes it is strained again through absorbent cotton on reaching the cooling room. In a majority of the dairies a cooler of some description is used; in a few, however, the milk is strained into cans standing in ice water. It is then bottled, packed in cases, and covered with crushed ice.

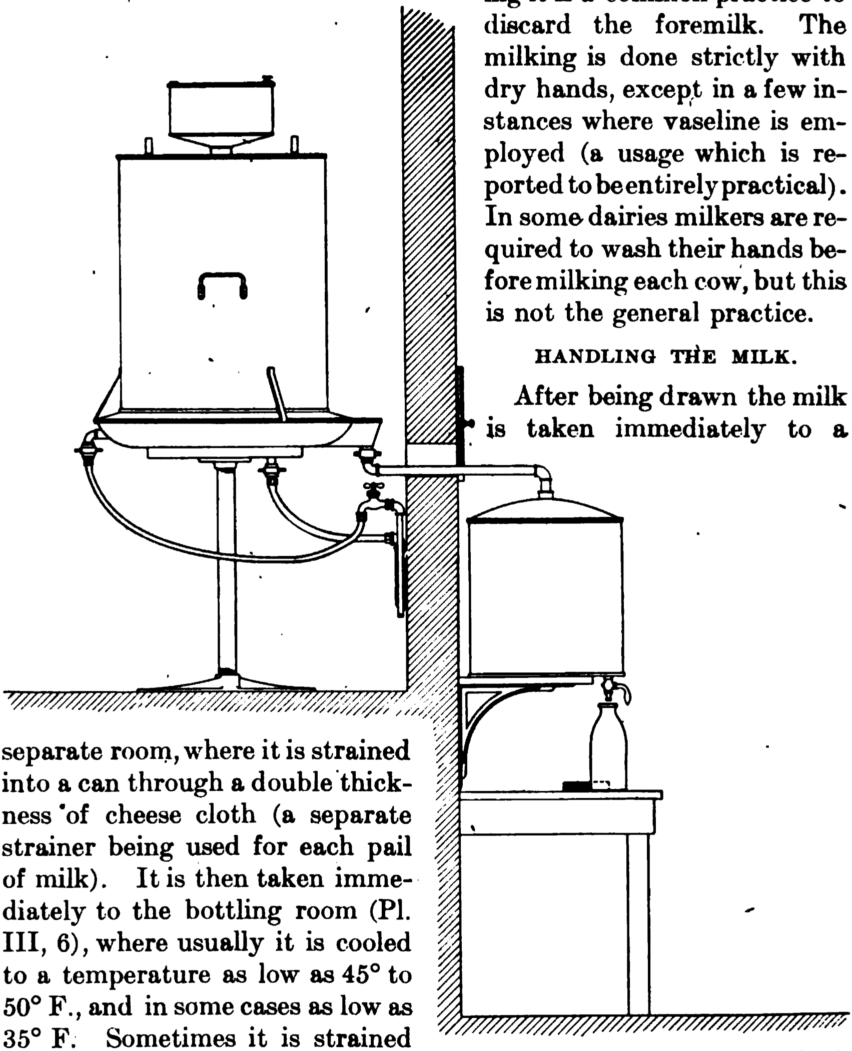


FIG. 1.—An arrangement of cooler and hand bottle filler.

Figure 1 shows an arrangement of cooler and hand bottle filler, and figure 2 is a floor plan for a small dairy house for handling certified milk. If the barn is sanitary the dairy house may be directly attached, the weigh room serving to separate the milk room from the barn. There is probably less danger to the quality of the milk in having the dairy connected with the barn (as shown in fig. 2). than in having these buildings separated by an open space through which the milk is carried after each cow is milked.

The cooler (parts of which are shown in Pl. V) is placed in the receiving room (designated as "weigh room" in fig. 2). After each cow is milked the milk is passed over the cooler and into the hand bottling receptacle in the bottling room. One man bottles the milk without assistance and is able to fill and cap 200 to 300 bottles an hour and place them in the storeroom. It will be seen that this arrangement facilitates prompt cooling and immediate bottling without exposing the milk. The apparatus is very simple, inexpensive (cost not exceeding $150), sanitary, and can be easily and quickly cleaned. It is understood that the apparatus shown in the illustration is designed for the small certified-milk producer with about 50 cows.

Considering the possibilities of producing certified milk with the inexpensive dairy house (fig. 2) and the apparatus required for cooling and bottling as described and illustrated (see p. 26), the small dairyman should be encouraged to produce certified milk.

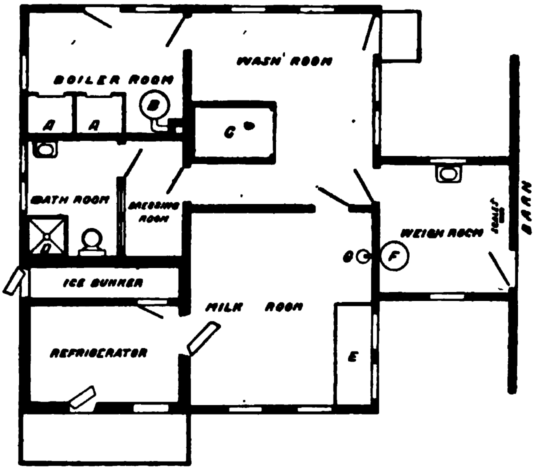


FIG. 2.—Dairy house for certified-milk plant with fifty cows. (*A A*, coal bunkers; *B*, boiler; *C*, sterilizer; *D*, shower bath; *E*, bottling table; *F*, cooler; *G*, receiving can.)

The milk coolers in some of the dairies are so constructed that the upper coils of pipe can be filled with hydrant or well water and the lower ones with ice water or brine. The top coils remove much of the animal heat, while the lower ones reduce the milk to a temperature of 35 to 40° F. As the milk is very much exposed in this room, the importance of the air being free from all impurities is apparent. In the best dairies the room is sterilized with steam preparatory to cooling the milk, and in some instances the air entering the room is filtered through absorbent cotton or a spray of water.

The milk from the cooler passes immediately into a tank connected with the bottling machine. Some plants are so arranged that the bottling machine, as well as the bottles, passes through a pressure steam sterilizer before entering the bottling room. Paper caps (made from wood pulp) are universally used on the bottles. The filled bottles are rapidly packed in cases and covered with cracked ice. They are then put in cold storage, or in some cases transported immediately, the ice being renewed as often as necessary in transportation so that a low temperature is maintained until the product reaches the consumer. (See Pl. IV.)

STERILIZING CAPS FOR MILK BOTTLES.

It is important that the milk caps be kept sterile, otherwise the milk is contaminated immediately after being bottled. This is provided for in some instances by the milk commissions, which sterilize the caps and send them to the dairymen in pasteboard boxes, 100 caps in each box. Some dairymen sterilize their own caps by inclosing them in a galvanized iron box or a cloth bag and placing them in the sterilizer. Some use copper tubes for this purpose. (Fig. 3.) These are so constructed that the caps can be removed and placed in the bottles by touching only the edges.

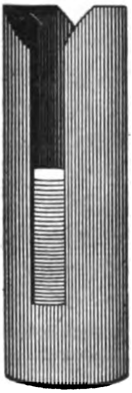


FIG. 3.—Copper case used in sterilizing milk caps.

COVERINGS AND SEALS FOR BOTTLES.

Some producers of certified milk use nothing for sealing the bottles but ordinary pulp caps stamped with the name of the commission and the date. Others use various coverings in addition to the ordinary cap, some of which are shown in Plate VI.

A parchment circle bearing the name of the dairy is frequently placed over the top of the bottle in addition to the pulp cap, and fastened with a rubber band. (Pl. VI, fig. 1, No. 2.) Another style consists of a tinfoil covering on the top of the bottle in addition to the ordinary cap. The covering is sometimes pasted down with a label, making a very neat package, but one too expensive for practical use. (See Pl. VI, fig. 1, No. 4.) The pulp cap sometimes leaks (Pl. VI, fig. 2, No. 4), allowing bacteria to enter.

Sometimes, in addition to the pulp cap, a metal cover is used which fits over the top of the bottle and is fastened with a wire and lead seal. (Pl. VI, fig. 1, No. 1.) While this method affords good protection to the milk, it adds unnecessary expense. However, there is nothing to prevent the pulp cap from leaking and molds from developing. (See Pl. VI, fig. 2, No. 1.)

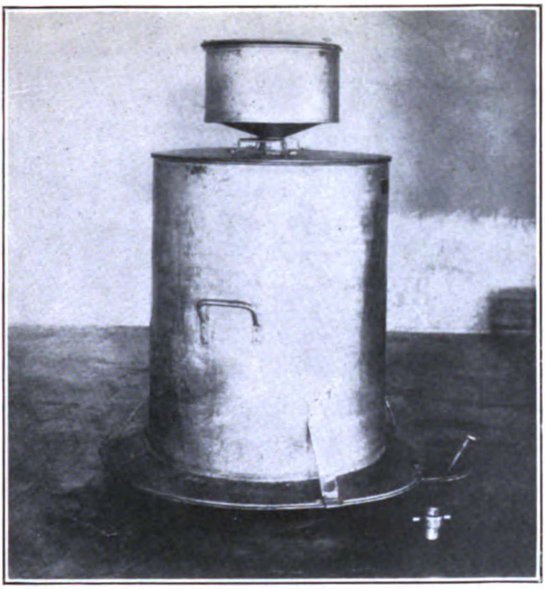


FIG. 1.—COVERED MILK COOLER.

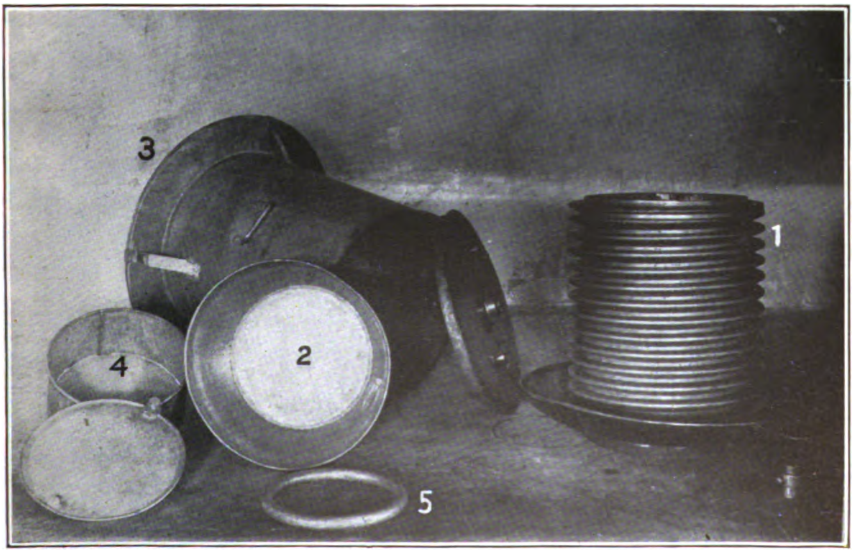


FIG. 2.—PARTS OF COOLER.

1. Cooler proper. Water passes through interior of coil, and milk over outer surface. 2. Receptacle placed on top of No. 1; has perforations in the bottom near the edge for distributing milk over the cooler. 3. Cover inclosing cooler. 4. Receptacle for receiving the milk and which also contains the strainer. The latter consists of a perforated plate which is put in first; next to this is placed a layer of cheese cloth, then a layer of absorbent cotton followed by another layer of cheese cloth and a perforated plate. 5. A copper ring, filled with lead and heavily tinned, placed on top of parts of strainer to hold them in position.

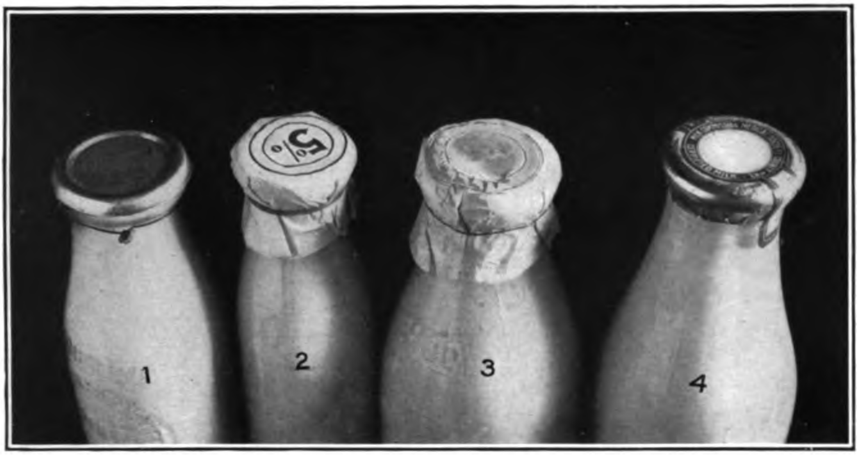


FIG. 1.—COVERINGS FOR BOTTLES OF CERTIFIED MILK.

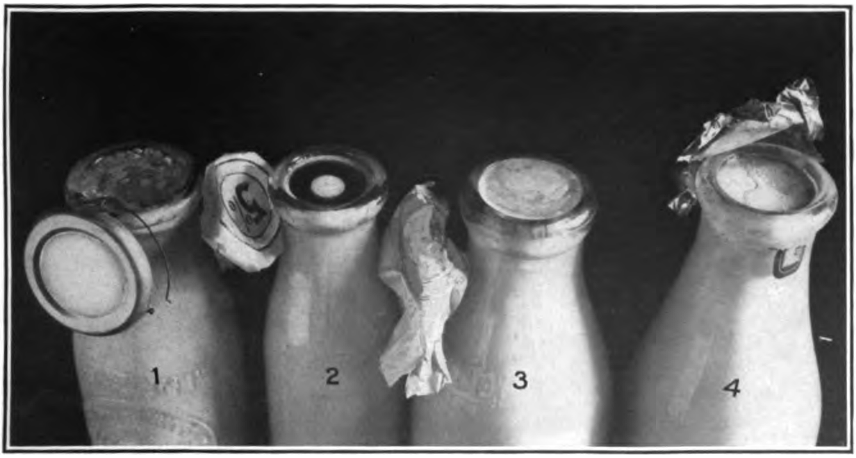


FIG. 2.—BOTTLES WITH OUTER COVERINGS REMOVED.

Still another method is to cover the paper cap with a plug of paraffin on which is placed by means of a rubber stamp the date on which the milk should be used. The whole is then covered with parchment paper fastened with a rubber band. This style is illustrated in Pl. VI (fig. 1, No. 3; and fig. 2, No. 3). The rubber stamp is supplied to each producer by the milk commission and is changed monthly. Every stamp has a secret mark so that all certified milk can be readily identified in the city. The stamp reads "To be sold and used {date]." It is practically impossible to tamper with this seal without the fact being detected. The paraffin has the advantage of sealing the bottle and preventing deception by refilling. It is also cheap, and altogether this makes a most desirable package.

MILK PAILS, STRAINERS, AND STOOLS.

The milk pails used in certified-milk plants present a great variety of styles. Generally speaking, they have a small opening (5 to 8 inches.) Some are provided with a strainer through which the milk passes in entering the pail. This consists, in some instances, of several thicknesses of cheese cloth, in others of both cheese cloth and absorbent cotton, and in still others of metal wire. One form of pail also serves the purpose of a stool. (Fig. 9.)

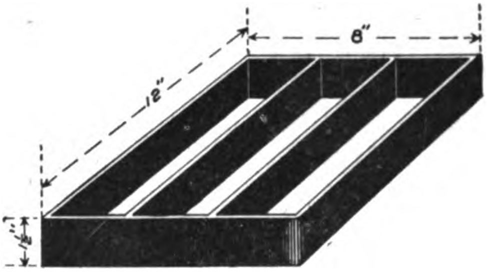


Fig. 4.—Metal frame on which milk pails are set in stable to keep them out of the dirt.

The styles of milk pails shown in figure 5 were reported as actually in use at certified-milk plants. No attempt has been made to illustrate all the kinds of pails in the trade. The cuts, however, give a good general idea of the forms commonly found on certified dairy farms. (Figs. 5, 6, and 7.)

No. 1 has the advantage of being stamped from one piece of tin. The strainer, however, is poorly constructed, having a metal sieve permanently soldered in the bottom, and the top rolled over, making it difficult to keep clean. This pail would doubtless give better results in fairly clean dairies if the strainer were discarded altogether.

No. 2 has a removable cover, cheese cloth being spread over top of pail before cover is put on. It is a fairly good pail, but the removable cover has no special advantage over the one-piece pail and it makes one more part to keep clean. The cover must be removed after each milking, thus adding to the danger of contamination.

No. 3 is similar to No. 1, except that it has a strainer simpler in construction and hence more readily cleaned.

No. 4 is a substantial small-top pail. It would be improved by a hood similar to that of No. 5. It is difficult for the milker to hold, on account of being smaller at the top than at the bottom.

No. 5 exhibits the best principles. There is no strainer attached, and the hood prevents dust and dirt from dropping into the milk when the pail is tipped in the position used in milking. It should be made of one piece of tin. It is, however, not as easy for the milker to hold as styles 1, 2, and 3.

No. 6 is a very popular pail with certified-milk producers. Absorbent cotton is placed in the top between two layers of cheese cloth, and this serves as a strainer during milking. The cap is removed from the opening at the right to pour out the milk. This pail altogether is a little complex and requires careful cleaning to keep it in good condition. The absorbent cotton also adds some expense. Clean dairies do not require a pail with a strainer, and if no strainer is used the extra spout is of no value.

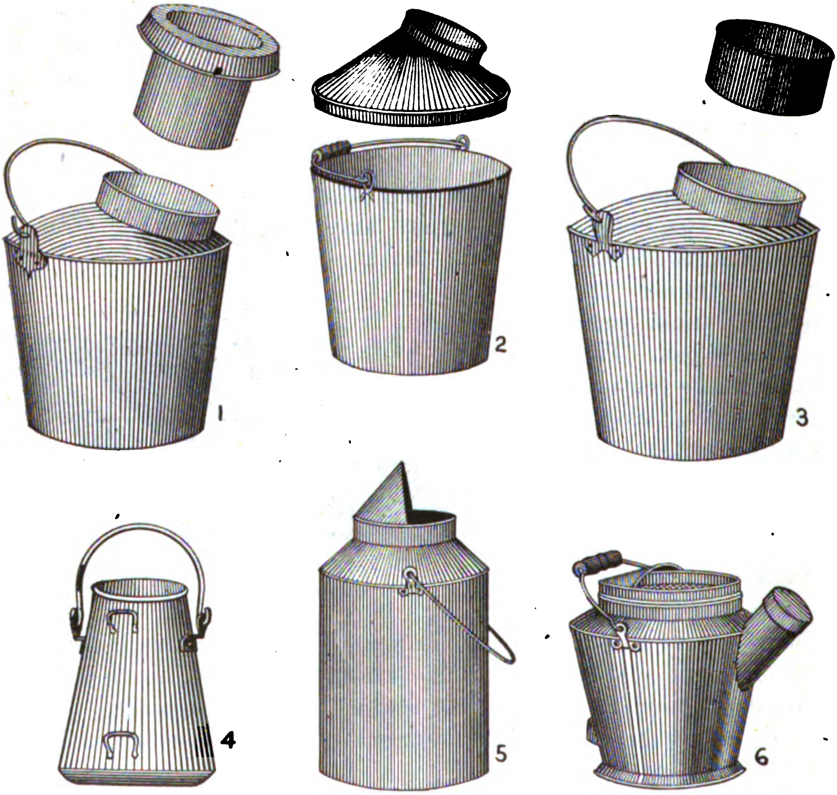


FIG. 5.—Some forms of milk pails used in certified dairies.

No. 7 is a porcelain pail with adjustable tin cover similar to No. 2. Cheese cloth is placed over the top of the pail before the cover is put on, and serves as a strainer.

No. 8 is an ordinary open pail with no provision for keeping out dirt. It should not be used in any dairy.

No. 9 is a good sanitary pail. It has a small top provided with a metal strainer. In certified dairies probably better results would be secured by leaving out the strainer. The pail would be improved if stamped from one piece of tin.

Nos. 10 and 11 illustrate the same pail, No. 11 showing a section of the interior. This pail is objectionable for the reason that the cover is carelessly soldered in, leaving an open seam (*a*) which collects dirt and is impossible to keep clean.

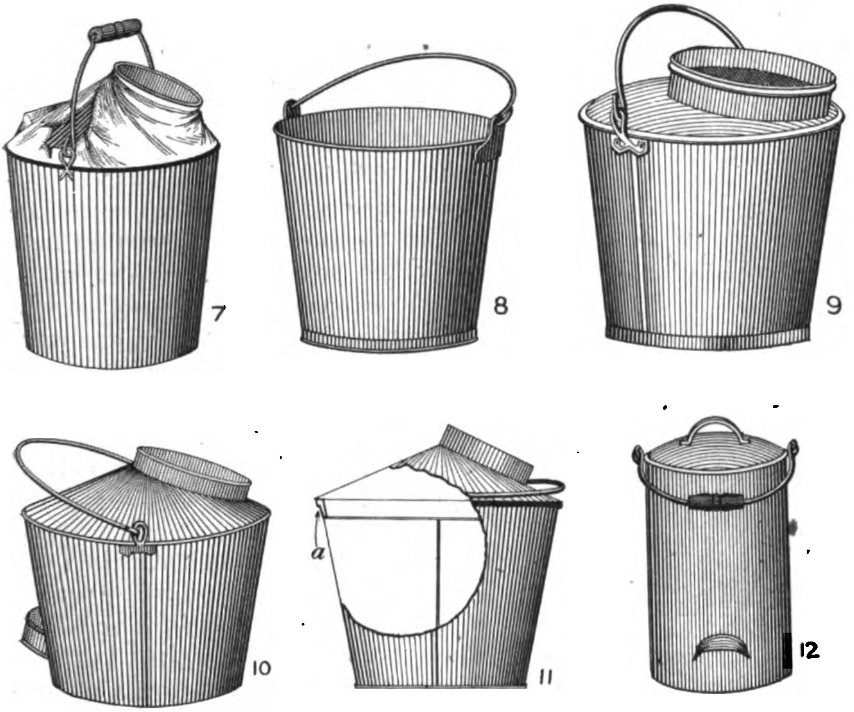


FIG. 6.—Additional forms of milk pails used in certified dairies.

No. 12 shows the shape of an ordinary cream can. The opening is too large and the can is not provided with a hood. The can has too many seams, and it is not ordinarily built strong enough for milking.

No. 13 is a good, sanitary milk pail. The height is convenient, and as the opening is on the side there is but little chance for dirt to fall in. The seams are well flushed with solder. The objection to this pail, if any, is the difficulty of seeing that all parts are clean.

No. 14 is a sanitary milk pail showing cup attached for holding the foremilk. The most objectionable feature of the pail is the difficulty of seeing whether all parts of the interior are clean.

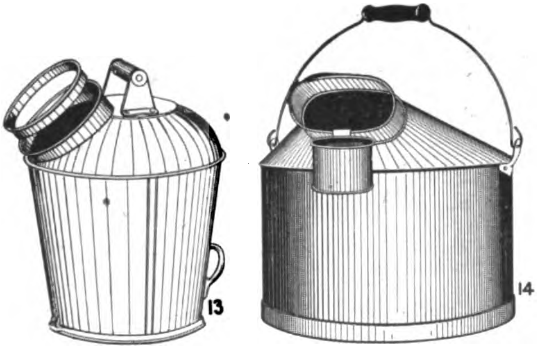


FIG. 7.—Two more forms of milk pails used in certified plants.

As already stated, there are other sanitary milk pails on the market which are not presented here simply because their use has not been reported in this investigation.

Aside from the strainers used in the pails, absorbent cotton is generally preferred. This is usually inclosed between two thicknesses of cheese cloth, a method which is found to be very practical.

The only object in having a strainer in a certified dairy is for safety. There should be no visible dirt or dust on the strainer, but in case a hair or any particles of dirt should accidentally fall into the milk the strainer prevents it from passing into the can and finally into the bottle. The strainer also acts as an indicator and shows whether or not the milking has been done in a cleanly manner. It is believed to be best not to have a strainer of any kind in the milk pail, as its absence has a tendency to make the milker use the utmost care in his work, because he knows that if any particles of dirt fall they will go directly into the milk. After milking each cow the milk should be strained through two or more thicknesses of cheese cloth or through sterilized cotton. Either one of these can be thrown away after use and there are no strainers to wash. Metal strainers are not necessary or desirable in a certified-milk plant. When they are used they should be so constructed that they can be taken apart for thorough cleaning.

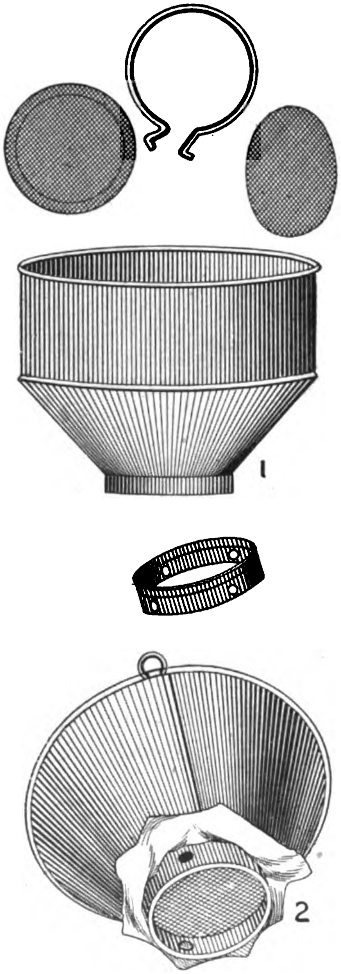


FIG. 8.—Form of strainer used in a few certified plants.

Figure 8 shows a form of strainer used in a few certified dairies. It has adjustable sieves which facilitate cleaning. While this style is commonly used where milk is more or less dirty, some simple form such as two or three thicknesses of cheese cloth which can be thrown away after straining each cow's milk is better. Metal parts are difficult to keep sterile and may add more bacteria than they remove.

The milk stools used in certified plants vary greatly in construction, style, and material. Some are constructed wholly of wood and some have metal legs and wooden seat; those in most common use are made of heavy galvanized iron; these will stand constant sterilizing and never wear out.

Figure 9 shows a number of forms of stools that have been reported in use at certified dairies.

No. 1 is a good type of sanitary stool made of metal. The ends of the pipes used for the legs are filled with lead, and there are no corners to collect dirt.

Nos. 2 and 4 are similar to No. 1, except that caps are screwed on the ends of the legs, making them slightly more difficult to keep clean.

No. 3 serves for both pail and milk stool. The cover, hoops, bail, etc., make it more difficult to keep clean than the simpler styles.

No. 5 is devised so that one end serves as a receptacle to hold the pail while the milker sits on the other end. As in the case of No. 3, this style is more difficult to keep in a sanitary condition than the simpler forms.

No. 6 is constructed entirely of iron, galvanized after being put together. It is simply constructed, having only a single leg. The base, however, furnishes a larger surface to keep clean.

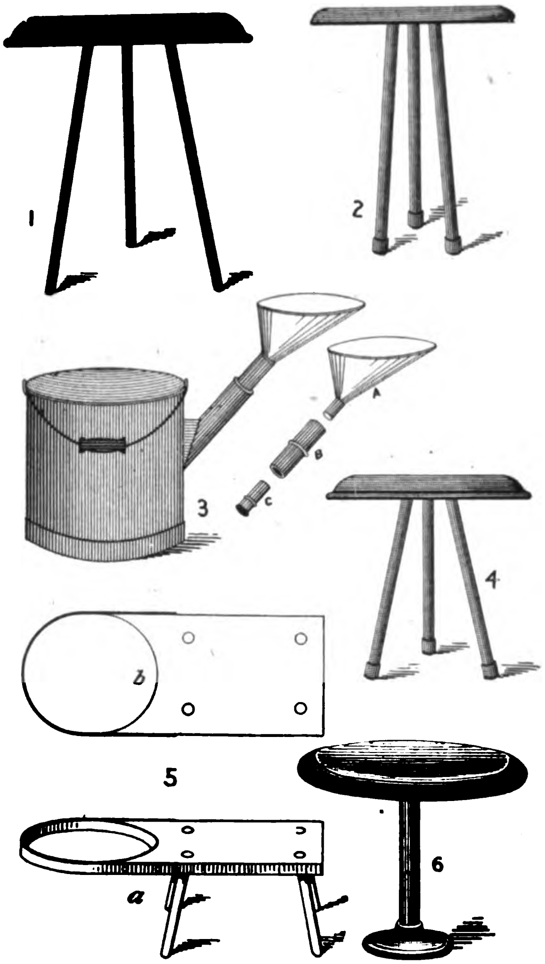


Fig. 9.—Milking stools used in certified dairies.

PRICES RECEIVED FOR CERTIFIED MILK.

The lowest price reported for certified milk delivered at the local railroad station was 5 to 5½ cents a quart in cans, the dealer paying the transportation charges. One producer bottles his milk and sells it for 6 cents a quart wholesale. The dealer furnishes the bottles and cases and pays the freight. The highest price received for certified milk bottled at the farm and delivered to the local station was 10 cents a quart. The retail price for certified milk ranges from 10 to 30 cents a quart, and the retail price of cream varies from 30 to 50 cents a quart. The reports received from the milk commissions show that prices received for certified milk average about 5 cents a quart higher than prices for ordinary market milk. It should be noted that the prices given here are largely wholesale or prices received by the dairymen, while those reported by the Commissions in another part of this bulletin are largely retail or prices paid by the consumer.

IS THE PRODUCTION OF CERTIFIED MILK PROFITABLE?

Eighteen certified milk producers reported the business profitable or fairly so. (See Table 2.) One stated that it was not profitable at less than 15 cents a quart. Several stated that it was profitable if conducted on a large scale. Nearness to market and facilities for transportation also affect the profit. Difficulty in securing competent help and lack of appreciation on the part of the public were reported by some to be drawbacks to their business. In many instances the business has not paid owing to the great expense for buildings and equipment, but much of this expense was entirely unnecessary. Sanitary conditions and extreme care are far more important requisites in the production of certified milk than fine architecture and expensive and superfluous apparatus.

SANITARY CONDITIONS OF CERTIFIED MILK DAIRIES.

In order to determine the sanitary conditions existing in certified milk dairies, sixteen were visited by a representative of the Dairy Division and scored on the basis of the official score card prepared and used by the Dairy Division. The result of the scoring is shown in Table 3.

TABLE 3.—*Detailed scores of sixteen certified dairy farms.*[a]

No. of dairy.	Cows (perfect score, 20).	Stables (perfect score, 25).	Milk house (perfect score, 20).	Milking (perfect score, 15).	Handling of milk (perfect score, 20).	Total score (perfect, 100).
1	20.00	13.00	19.00	12.00	15.00	79.00
2	20.00	17.00	15.00	13.00	16.00	81.00
3	19.50	20.50	16.00	12.00	15.00	83.00
4	20.00	22.50	17.00	12.00	15.00	86.50
5	20.00	23.00	17.00	13.00	19.00	92.00
6	20.00	19.00	20.00	15.00	20.00	94.00
7	19.75	23.50	20.00	14.00	18.00	95.25
8	20.00	22.00	20.00	15.00	20.00	97.00
9	20.00	21.90	19.60	15.00	20.00	96.50
10	20.00	22.30	20.00	15.00	20.00	97.30
11	19.25	23.50	20.00	15.00	20.00	97.75
12	20.00	24.00	19.50	15.00	20.00	98.50
13	20.00	24.00	20.00	15.00	20.00	99.00
14	20.00	24.50	19.50	15.00	20.00	99.00
15	20.00	24.50	20.00	15.00	20.00	99.50
16	20.00	24.50	20.00	15.00	20.00	99.50
Average	19.90	21.80	18.90	14.10	18.60	93.40
Per cent of perfect score	99.5	87.2	94.5	94	93	93.40

[a] The farms were scored in most instances by Dr. E. M. Santee, assistant dairyman.

A study of the scores shows the cows to be in almost perfect condition, the average score being 19.9 points out of a possible 20. All the animals had been tested with tuberculin.

The greatest defects were found in the stables, some showing poor construction, while others were scored off a point or two for lack of cleanliness. Occasionally the light and the ventilation were poor. The average score for the stables was 21.8, perfect being 25.

The condition of the milk houses was generally good. Seven had slight deficiencies in construction and 5 were scored off a point or two on equipment. Fourteen of the 16 were given a perfect score for cleanliness, 14 were perfect on utensils, and 15 had good water supply.

The methods of milking were good. Clean, white suits were worn by the milkers in nearly all cases, and proper attention was given to the udders and flanks of the cows before milking. The average score for milking was 14.1 points out of a possible 15. Ten dairies received a perfect score.

The milk was handled by the most approved methods in most instances, and promptly cooled to a temperature low enough to keep the bacteria in check. The average score for handling the milk was 18.6 out of a possible 20. Ten dairies received a perfect score.

Averaging the scores for all the conditions, we find 1 dairy below 80, 3 over 80 and less than 90, and 12 over 90; 2 scored 99, and 2, 99.5. The average score for all dairies was 93.4. Comparing these conditions with the average of some 2,000 dairies producing ordinary market milk for city consumption, we find a striking contrast, the average score for the latter being about 50.

THE QUALITY OF CERTIFIED MILK.

It was arranged to have 12 samples of certified milk sent to Washington from various points for analysis. These were tested for solids, fat, bacteria, acidity, and flavor; and were scored on the basis of a score card prepared for this purpose. Table 4 shows the results of the scoring.

TABLE 4.—*Analyses of samples of certified milk (four days old) shipped to Washington from points in New York, New Jersey, Pennsylvania, Ohio, and Kentucky.*[a]

DESCRIPTIVE SCORE.

Sample No.	Flavor.	Fat.	Solids not fat.	Total solids.	Acidity.	Total bacteria per c. c.	Condition of package and contents.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		
1	Good	6.50	9.80	16.30	.198	3,800	Trace of foreign matter.
2	Good	3.75	9.75	13.50	.216	1,000	Do.
3	Good	6.30	9.76	16.06	.199	4,800	Do.
4	Slight silage taint.	5.05	8.88	13.93	.180	3,500	Good.
5	Silage and salty	[b] 5.60	9.99	15.59	.201	1,820	Trace of foreign matter.
6	Fair	5.20	8.79	13.99	.198	3,050	Do.
7	Slightly bitter	4.50	9.40	13.90	.189	10,900	Good.
8	Slight silage flavor	5.00	9.00	14.00	.203	7,700	Trace of foreign matter.
9	Good	4.60	9.17	13.77	.187	3,600	Good.
10	Good	4.50	9.02	13.52	.198	280	Do.
11	Slight silage flavor	4.70	9.40	14.10	.197	[c] 19,000	Do.
12	do	4.70	8.94	13.64	.201	2,750	Do.
	Average	5.03	9.33	14.36	.197	5,183	

[a] The samples were analyzed by Ivan C. Weld, assistant dairyman in the Dairy Division, who also assisted in the scoring.

[b] Sold for 5 per cent milk.

[c] Analyzed and scored when five days old, owing to delay in transportation.

TABLE 4.—*Analyses of samples of certified milk (four days old) shipped to Washington from points in New York, New Jersey, Pennsylvania, Ohio, and Kentucky*—Con.

NUMERICAL SCORE.

Sample No.	Flavor (perfect score, 40).	Composition (perfect score, 25).	Bacteria (perfect score, 20).	Acidity (perfect score, 5).	Appearance of package and contents (perfect score, 10).	Total score (perfect, 100).
1	36.50	17.00	16.00	3.50	9.00	82.00
2	37.50	25.00	20.00	1.50	9.00	93.00
3	36.00	17.00	15.00	3.50	9.50	81.00
4	31.50	22.00	16.00	5.00	10.00	84.50
5	32.00	25.00	18.00	3.00	9.50	87.50
6	33.00	22.00	16.00	3.50	9.50	84.00
7	35.00	25.00	9.00	4.50	10.00	83.50
8	35.25	23.00	12.00	2.50	9.50	82.25
9	36.50	24.00	16.00	4.50	10.00	91.00
10	36.25	25.00	20.00	3.50	10.00	94.75
11	35.00	24.00	5.00	3.50	10.00	77.25
12	36.00	24.00	17.00	3.00	10.00	90.00
Average	35.00	22.75	15.00	3.46	9.70	86.00

The scores show that the milk was generally of good quality. Five samples showed a slight silage taint, which reduced the score somewhat on this point. From observations made by the writer it is believed this flavor was transmitted to the milk more frequently from silage odors in the barn during milking than from feeding silage. One sample was slightly salty and another slightly bitter. The average score for flavor was 35 points out of a possible 40.

The fat in the milk with one exception reached 4 per cent or higher. Four samples were above 5 per cent, two of these being above 6. These considerably exceeded the limit specified by the commissions. While the customer receiving this high quality of milk would have the advantage in quality, it is believed that the fat in certified milk should be kept within the limits specified by the commissions. As stated on the score card, 1 point is deducted for every one-fourth per cent variation from the limits of 3.5 and 4.5 per cent, hence some scores were reduced quite materially for this reason. The average for all the samples was 5.03 per cent, solids not fat 9.33, and total solids 14.36. The average score for composition was 22.75 points out of a possible 25.

All of the samples were cut a little for excessive acidity, but it should be stated that the milk was four days old when scored, and in some cases it had been shipped without ice. The average acidity was 0.197 per cent, and the average score for acidity was 3.46 points out of a possible 5.

The bacteria in the milk showed a great variation in numbers, the highest number being 19,000 per cubic centimeter and the lowest 280. Deductions were made for counts exceeding 1,000 per cubic centimeter on the basis of the score card. The average count was 5,183 and the average score for bacteria was 15 points out of a possible 20.

The style of the packages and the appearance of the contents so far as foreign matter was concerned were generally good. Six of the samples had a slight trace of sediment. The average score was 9.7 points out of a possible 10.

The total score for all samples was 86 on the basis of 100 for perfect. One hundred and forty-four samples of market milk recently scored by the Dairy Division averaged 81.4, indicating that the quality of milk sold as certified was quite superior to the ordinary product in spite of the fact that it was from three to four days old when scored, while the market milk was scored the same day it was produced.

CERTIFIED MILK AND MARKET MILK COMPARED.

As far as the chemical composition is concerned, certified milk does not differ materially from ordinary market milk. The milk commissions require that the fat and total solids shall come within certain limits, and for this reason there is but little variation in the chemical composition of certified milk. The standards are not high for the reason that milk containing about 4 per cent of fat is considered to be the best for immediate consumption. As stated elsewhere, many of the herds in certified-milk dairies are composed of grade cows and do not produce milk of more than the average richness.

When we compare the bacterial content of certified and market milk we find a very striking difference. The bacteria in the average milk supply of our large cities exceed 500,000 to the cubic centimeter, while the bacteria in certified milk seldom exceed 30,000 to the cubic centimeter and in most instances average less than 10,000. There have been some cases where commissions have reported that no bacteria were shown to be present by the ordinary methods used for their detection. Liquefying, putrefactive, and pus-forming bacteria are seldom present in large numbers; in fact the contracts of some commissions with the producers specify that the milk shall not contain pathogenic bacteria or more than a limited number of pus cells to the cubic centimeter.

KEEPING QUALITIES OF CERTIFIED MILK.

As would naturally be expected, certified milk with its small number of bacteria will keep sweet for a long time. The theory that clean milk should have a long keeping quality works out in practice. Instances are on record where certified milk has been taken on an ocean voyage and not only brought back in good condition but kept sweet until thirty days old. In fact it is now a common practice for people when crossing the water or taking a long land journey with infants to take several cases of certified milk with them. They are then reasonably sure of having a constant supply of sweet milk for several days. Some producers who guarantee their milk have offices in London as well as in this country so that a supply of fresh milk can be secured by voyagers going in either direction. This has been a great convenience and has given comfort to many people. Again, a number of certified-milk dairies in the United States sent exhibits of milk to the Paris Exposition in 1900. The milk kept perfectly sweet for two weeks and in some instances 18 days after being bottled and after a summer journey of 3,000 to 4,000 miles. Regular delivery bottles were used, the only extra precaution being to use two paper caps instead of one, and to cover the caps with paraffin so as to exclude the air. Of course the milk was carefully packed in ice for shipment, but this was the only means used for preservation.

The results of the milk and cream contest at the National Dairy Show held in Chicago in February, 1906,[a] were of interest in showing the keeping quality of certified milk and cream. Some of the milk exhibited was shipped over 1,000 miles and was still sweet after five weeks, and in one instance seven weeks, from the time it was shipped. These results tend to show that what is needed more than anything else, in order to improve the milk supply, is cleaner milk.

IS CERTIFIED MILK WORTH THE EXTRA COST?

In view of the extreme care and greater expense required in the production of certified milk, the question is sometimes raised as to whether it is worth the labor and pains necessary to produce it. It must be conceded that pure milk is of vital importance in the feeding of infants. The best way to produce it is by the methods commonly practiced in certified-milk plants as already outlined in this bulletin. The result of feeding such milk to infants and children in our cities, as shown in the decrease in the death rate, is a matter of common knowledge. Further, with more refined ideas of living, there is a growing demand for milk of the highest quality that can be produced. Naturally, with the careful methods used in its production, certified milk costs more than ordinary market milk, and the price charged for it is correspondingly higher. In spite of this advanced price, however, a number of certified dairies have failed to make a profit.

Certified milk, produced under the direction of a reliable milk commission, is worth more than ordinary market milk for several reasons: (1) It is free from disease-producing bacteria, and all other germs are reduced to a minimum. (2) It is free from high acidity and pathogenic germs which lead to stomach derangements and kindred troubles. (3) The customer can always depend upon his milk coming from the same farm, the same herd of cows, subjected to the same treatment, and having the same quality. The fat content is guaranteed not to vary outside of narrow limits; hence the milk is always of good quality. (4) Cleanliness and cold are the only preservatives used. (5) It is a safe food for infants and people with delicate digestion. (6) It is the natural product of the cow, and has not been subjected to any treatment which affects its digestibility or changes its character. (7) It is reasonably free from foreign odors and objectionable flavors.

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[a] Bureau of Animal Industry Bulletin 87.

THE FUTURE OF THE CERTIFIED-MILK INDUSTRY.

The production and sale of certified milk will probably never amount to more than a small fraction of the total milk consumed. It is believed, however, that the demand for this class of milk will increase, not only for infants and persons of delicate health, but for people who appreciate a good product and want the best. There is over a score of cities at the present time each of which is supplied with certified milk from one or more dairies, and it is believed that most cities of a population of 25,000 to 50,000 or more would support a certified-milk dairy if the product were properly advertised and its merits generally known to the public. Physicians assist greatly in the sale of certified milk, and, as a number of them are usually members of the milk commissions in the various cities, they are thoroughly acquainted with the conditions under which the milk is produced and freely recommend its use.

AN ECONOMICAL METHOD OF PRODUCING CERTIFIED MILK.[a]

This description is not intended to interest those who are desirous of building show plants, but only those who want to produce certified milk of superior quality at the minimum cost for buildings, equipment, and operation. There are a few essential points in the production and handling of certified milk which must be observed. If these details are strictly adhered to, the quality of the milk, so far as the bacterial content is concerned, is assured.

The following are the points to be regarded as the most important:

1. The health of the cows.
2. The sanitary construction of the barn.
3. The sanitary condition of the barn.
4. The sanitary condition of the cows.
5. The sanitary condition of utensils.
6. The sanitary condition of clothing.
7. Sanitary methods of milking.
8. Few utensils, simple in construction.
9. Rapidity of cooling.
10. Sanitary bottling room.

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[a] This article was prepared by B. D. White, assistant dairyman in the Dairy Division, at the author's request, and shows an economical method for the production of certified milk as practiced several years by Mr. White when superintendent of a certified dairy in Minnesota.

11. Rapid bottling into sterilized bottles.

12. Keeping filled bottles covered with chopped ice from time of filling to time of delivery to consumers.

No attempt will be made to theorize, but the writer will simply state his practical experience and the results obtained under such conditions.

Health of the cows.—Every cow was tested at least once each year for tuberculosis by a competent veterinarian, and new animals to be placed in the herd were tested, then isolated for three months and tested again. Herds have been contaminated by purchased animals which did not react when purchased, but showed a decided reaction a few months thereafter, thus showing the necessity for this practice. The cows were watched for other diseases and ailments, and when one showed symptoms of any trouble she was immediately removed from the herd and her milk was rejected.

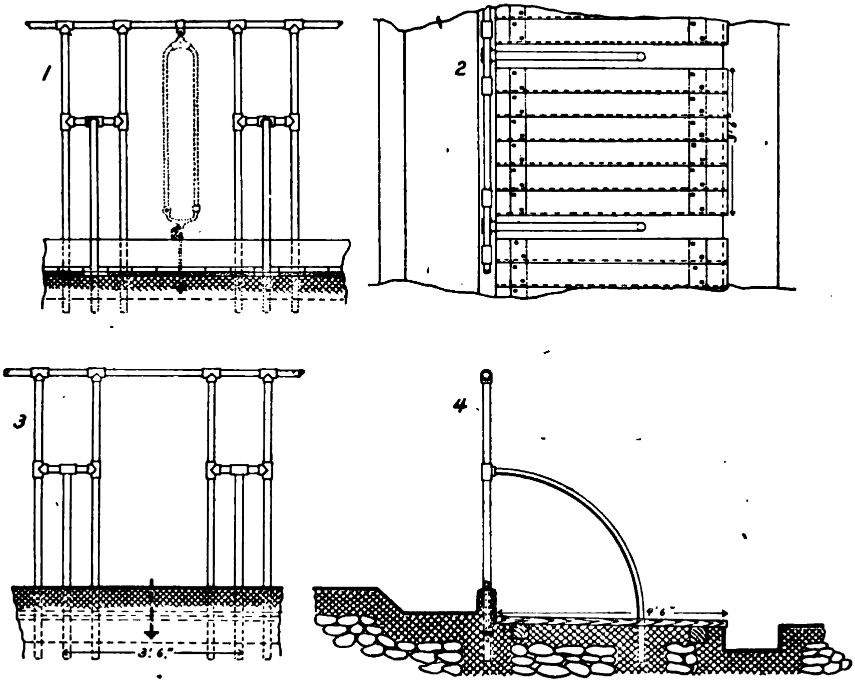

FIG. 10.—Stall with panel wooden floor.

Sanitary construction of barn.—The barn was a one-story structure of wood with plenty of light and provided with the King system of ventilation. The floor, wall, and manger were of cement; the ceiling was lath and plaster; swing stanchions were used for ties. It was found that the cement floor was too hard for the cows to stand on and was the cause of various troubles, such as garget, etc.; consequently it was later covered with 2-inch matched pine flooring, which gave better results.

In building again we would substitute panel floors for stalls, as illustrated in figure 10. Two pieces 4 by 4 inches by 3 feet are laid in the concrete, and a panel 3 feet wide made of 2 by 6-inch matched plank nailed to them. The panel projects over the gutter about 1 inch. A space of 6 inches is left between panels which is cemented level with the top of the plank. This admits of taking up a panel and putting in a new one without disturbing the rest of the floor. In putting down a floor in a new barn, or in replacing an old floor, it is recommended that tar be used in the joints and on the lower surface of the floor.

In the construction of a barn intended for the production of certified milk care should be taken to have as few posts as possible, and preferably no cross beams or braces should be exposed. The interior should be smooth with no place for the lodgment of dust.

Sanitary condition of the barn.—With the construction of such character that a barn may be kept clean, it only remains to use energy, water, and washing powder.

Sanitary condition of cows.—The cows as well as the barn must be kept clean. Experience has shown that the sanitary condition of the cows has as much to do with the bacterial content of the milk as any other factor. The method used was first to place the cows in a stall according to their size, to have sufficient bedding to keep them clean and comfortable, to keep the hair short in the region of the udder, to groom the cows every day, to wash them before every milking with clean, warm water and a brush, and just before milking each cow to clean the udder again with a clean wet towel. During fly time the tails of three cows (the one to be milked and the one on either side) were fastened with cow-tail holders. (See fig. 11.) After the cows were washed a small chain was fastened across the stanchions under the cows' necks to prevent them from lying down; after they were milked the chains were unfastened and the cows were allowed to lie down.

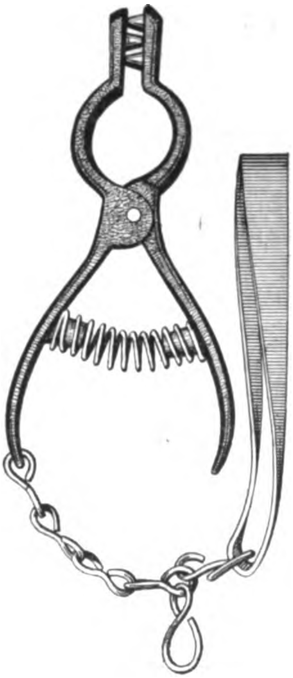

FIG. 11.—Cow-tail holder. The pincers snap around the cow's tail and the rubber band is passed around the leg and hooked into the open link on the chain.

The manure was not removed immediately before milking, and nothing was done which would raise a dust, as dust is one of the most prolific sources of milk contamination.

Sanitary condition of utensils.—All utensils with which the milk came in contact were washed, rinsed, and steamed, or sterilized in a pressure sterilizer.

Sanitary condition of clothing.—Milking suits were provided which consisted of white duck trousers, a black belt, and a khaki shirt, these making a neat and sanitary uniform. During the summer months the sleeves of the shirts were rolled up to or above the elbows. These suits were washed twice a week. With tight-fitting clothes there is less danger of contamination than with loose coats.

Sanitary method of milking.—With a clean barn, clean and healthy cows, clean utensils, and milkers wearing clean clothes, all that remains is care. However, it may be mentioned that it was the practice to wash the hands thoroughly before milking, and each milker was provided with an individual towel which was used only once. After the hands were washed and dried and a small amount of vaseline was rubbed on the palms, each milker took a pail, which had been previously sterilized by steam, and a clean metal milking stool, and proceeded to the stable with stool in one hand and pail in the other. The milkers did not touch the cows with their hands, except the teats. Care was taken in holding the pail (which was of the style shown in fig. 6, No. 9, except that the strainer was discarded) at an angle, so that there was but little if any chance for dirt to drop into the pail. After milking each cow the milker immediately proceeded to the milk room, carrying the pail with its opening away from him. The top of the pail was brushed with a clean damp cloth, and then the milk was poured into the covered receptacle, from which it flowed over the cooler, which was in the milk room attached to the barn. The milker then washed his hands in clean water and dried them with a clean towel and returned to milk another cow. The foremilk from each cow was caught in a separate receptacle and discarded.

Utensils and equipment.—The plant was originally equipped with the most elaborate apparatus money could buy, but after a thorough trial with poor results it was practically all discarded, including sterilizer for milking suits, large open cooler with many receptacles, conductors, etc., and elaborate anterooms connected with washrooms and baths. Theoretically and for show purposes this appeared all right, but it had no place in practice. When simpler apparatus was installed and simpler methods were practiced no difficulty was experienced in keeping the bacterial content down to an average of 2,000 per cubic centimeter.

Cooling.—Experience leads us to believe that the rapidity with which milk is cooled has a wonderful influence in keeping down the bacteria. Instead of drawing the milk and placing it in a can and when the can is full sending it to the dairy house to be passed through and over the surface of several different contrivances to be strained, cooled, and conducted to the bottling machine, the cooling was effected within 60 seconds from the time the milk was drawn from the cows.

The temperature of the milk was reduced to within 2 degrees of the temperature of the water passing through the cooler. The style of cooler is shown in Plate V. From this point the milk was conveyed to the milk house or bottling room when convenient, as the low temperature of the milk would permit holding it without danger of increasing the bacteria.

Sanitary bottling room.—Too much money was expended for a so-called bottling room which was insulated and provided with double windows which could not be opened. There being no intake for fresh air for fear of contaminating the room, when the ventilating system did not work, the room was hot and damp. It is only necessary to keep a room closed during the process of bottling, hence expensive insulation and double windows are unnecessary. An ordinary cement or plastered room, kept clean and with the floor moistened before bottling, will answer all purposes, provided the milk is not exposed in the room, which it need not be.

Bottling.—The bottles into which the milk was put were sterilized and the milk was bottled as quickly as possible; the filled bottles were covered with crushed ice until delivered to the consumers.

Analyses of product.—The following bacteria counts of the milk supplied by the dairy just described have been reported. They are certified to by Dr. F. F. Wesbrook, director of the laboratories of the Minnesota State Board of Health, and A. P. McDaniel, assistant bacteriologist. The tests were made with milk thirty-six hours old taken from delivery wagons.

Date.	Colonies.	Date.	Colonies.
	Per c. c.		*Per c. c.*
January 8	650	March 30	900
January 15	1,200	April 6	2,000
January 20	2,500	April 6	700
January 20	800	April 13	4,000
January 29	2,900	April 19	1,200
January 31	2,900	April 26	145
February 10	1,500	May 13	480
February 12	1,600	May 25	500
February 17	1,500	May 25	2,100
February 26	700	June 2	570
February 26	1,800	June 10	1,900
March 18	2,800	June 16	420
March 23	500	June 21	1,400
March 24	600	June 23	850

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Issued June 27, 1908.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 105.

A. D. MELVIN, CHIEF OF BUREAU.

VARIETIES OF CHEESE:

DESCRIPTIONS AND ANALYSES.

BY

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AND

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1908.

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Milk: L. A. Rogers, bacteriological chemist; C. R. Potteiger, dairy bacteriologist.

Organization and management investigations.

Creameries, drafting and designing: B. D. White, assistant dairyman, in charge; C. W. Fryhofer, scientific assistant; H. J. Credicott and J. G. Winkjer, assistant dairymen; Robert McAdam, inspector; K. E. Parks, architect.

Market milk service: C. B. Lane, assistant chief, in charge; G. M. Whitaker, dairy inspector; Ivan C. Weld, assistant dairyman.

Renovated butter inspection.

M. W. Lang, dairy inspector, in charge, 22 Fifth avenue, room 510, Chicago, Ill.; Levi Wells, dairy inspector, 6 Harrison street, New York, N. Y.; S. B. Willis and H. P. Olsen, deputy inspectors.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., January 18, 1908.

Sir: I have the honor to transmit herewith, and to recommend for publication as a bulletin of this Bureau, a manuscript entitled "Varieties of Cheese: Descriptions and Analyses." This paper was prepared under the direction of the chief of the Dairy Division by C. F. Doane, assistant dairyman in that division, and H. W. Lawson, of the Office of Experiment Stations.

The work is a compilation of descriptions and analyses of all the varieties of domestic and foreign cheese about which it has been possible to obtain such information in the literature bearing upon the subject. In a number of cases only meager details could be secured, and owing to the size of the work the descriptions are necessarily of a very condensed nature.

Acknowledgment is made of the courtesies and assistance extended by the Office of Experiment Stations in the preparation of this bulletin.

Respectfully,

A. D. Melvin,
Chief of Bureau.

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VARIETIES OF CHEESE: DESCRIPTIONS AND ANALYSES.

INTRODUCTION.

The amount of cheese imported into the United States is increasing rapidly. During the 6 years from 1900 to 1905, inclusive, the value of the imports increased from $1,946,033 to $3,875,161. Italy and Switzerland supplied the bulk of this cheese, most of the remainder coming from France and Holland. The best known of the varieties of cheese imported were the Parmesan and Gorgonzola from Italy, the Emmental from Switzerland, the Roquefort, Camembert, and Brie from France, and the Edam from Holland. The growing demand for cheese is not, however, confined to these well-known varieties, much interest being manifested in many kinds as yet of very little commercial importance but highly esteemed in the localities where produced.

Attempts have long been made in this country to imitate some of the European varieties and in some instances the results have been decidedly successful. The manufacture of Swiss, or Emmental, and of Limburg types has become well established. The investigations conducted at the Storrs Agricultural Experiment Station in Connecticut have shown that cheese of the Camembert type, equal in every way to the imported article, may be produced in the United States. This Department is cooperating in investigations of this kind and recently results have been obtained which make it practically certain that a cheese of the nature of Roquefort or Stilton can likewise be produced in this country.

Information concerning the manufacture and composition of the numerous varieties of cheese is not very accessible to English readers and the apparent need of some work of reference, in connection at least with the importation and home production of cheese, has, therefore, led to the preparation of the descriptive notes and the compilation of the analytical data contained in this bulletin.

The descriptions are, for the most part, based upon data contained in treatises on dairying and in articles in foreign periodicals. While in many instances they are very incomplete and possibly at times inaccurate, they nevertheless contain in condensed form practically all the important information that it has been possible to secure in an extended search through the literature relating in any way to the subject. Owing to the large number of publications consulted, it has seemed impracticable to give references to the descriptive matter.

The analyses have been compiled in most instances from the original publications. In all cases, however, the sources of the data have been given in the list of references which follows the table of analyses. No effort has been made to collect the numerous analyses of filled cheese, and in the case of American Cheddar cheese only a part of the available data has been included in the compilation.

DESCRIPTIONS OF VARIETIES OF CHEESE.

ABERTAM.

This is a hard rennet cheese made from sheep's milk in the region of Carlsbad, Bohemia.

ALEMTEJO.

This name is applied to rather soft cheeses made in the province of Alemtejo, Portugal. They are cylindrical in shape and are made in three sizes averaging in weight about 2 ounces, 1 pound, and 4 pounds, respectively. They are made for the most part from the milk of sheep, though goat's milk is often added, especially for the smaller sizes. The milk is warmed and curdled usually with an extract prepared from the flowers of a kind of thistle. The cheeses are ripened for several weeks.

ALPIN.

This is a kind of Mont d'Or cheese made in the Alpine regions of France. It is also known as Clérimbert. The milk is coagulated with rennet at 80° F. in two hours. The curd is dipped into molds 3 to 4 inches in diameter and 2½ inches in height. The cheese is allowed to drain and is turned several times during one day, after which it is salted and ripened for eight to fifteen days.

ALTENBURG.

This is a goat's-milk cheese made in Germany, where it is known as Altenburger Ziegenkäse. A cheese is 8 inches in diameter, 1 to 2 inches in thickness, and weighs about 2 pounds.

AMBERT.

This cheese, known as Fourme d'Ambert, is a cylindrical-shaped imitation Roquefort cheese made from cow's milk. It is said to differ from other forms of blue or imitation Roquefort cheese made in the southeastern part of France in that the salt is mixed with the curd rather than rubbed on the surface of the cheese.

ANCIEN IMPÉRIAL.

The curd is prepared in the same manner for this cheese as for Neufchâtel. The cheese is about 2 inches square and one-half inch thick. It is also known as Petit Carré and when ripened as Carré Affiné. The cheese is sold and consumed both while fresh and after ripening. The ripening process is not essentially different from that of Neufchâtel.

APPENZELL.

This cheese, which is very similar to Emmental, is made in the Canton of Appenzell, Switzerland, and also in Bavaria and Baden. It is usually made of skim milk but sometimes of whole milk.

BACKSTEIN.

Backstein, meaning brick, is so called from its shape, but it is not identical with the Brick cheese made in the United States. The process of manufacture is similar to that of Limburg.

BANBURY.

This was a soft, rich cheese, very popular in England in the early part of the nineteenth century. It was a cylindrical cheese about 1 inch thick.

BARBEREY.

This is a soft rennet cheese resembling Camembert and deriving its name from the village of Barberey near Troyes, France. It is also commonly known as Fromage de Troyes. The milk while still fresh and warm is coagulated with rennet, the time allowed being usually about four hours. The uncut curd is put into a wooden mold having a perforated bottom. After draining for three hours the cheese is turned into an earthenware mold, the wooden one being removed after twenty-four hours. The cheeses are salted, dried in a well-ventilated room, and ripened for about three weeks, usually in a subterranean curing room. In summer the cheese is often sold without ripening. A cheese is 5 to 6 inches in diameter and 1½ inches in thickness.

BATTLEMAT.

This is an Emmental cheese made in the Canton of Tessin, Switzerland, in the western part of Austria, and in the northern part of Italy. It is recommended for localities where a great quantity of milk can not be obtained. The cheese is circular in form, about 16 inches in diameter and 4 inches high, and weighs from 40 to 80 pounds. It is cooked at a slightly lower temperature than the Emmental and is a little softer when ripened. It ripens more rapidly than the Emmental, being ready for market in about four months.

BAUDEN.

Baudenkäse is a sour-milk cheese made in the herders' huts in the mountains between Bohemia and Silesia in essentially the same manner as Harzkäse. It is made up in two forms, one conical with a diameter and a height of 3½ inches, and the other cylindrical, with a diameter of 5 inches and a height of 2½ inches. It is also known locally as Koppenkäse.

BELGIAN COOKED.

The milk which has been allowed to curdle spontaneously is skimmed and the curd heated to 135° to 140° F. and then placed in a cloth and allowed to drain. When dry it is thoroughly kneaded by hand and is allowed to undergo fermentation, which takes ordinarily from ten to fourteen days in winter and six to eight days in summer. When the fermentation is complete, cream and salt are added and the mixture is heated gently and stirred until homogeneous, when it is put into molds and allowed to ripen for eight days longer. A cheese ordinarily weighs about 3½ pounds. It is not essentially different from other forms of cooked cheese.

BELLELAY.

This is a soft rennet cheese made from whole milk and sometimes called Tête de Moine, and Monk's Head. This cheese originated with the monks of the Canton of Bern, Switzerland, in the fifteenth century, and is made exclusively in that locality at the present time.

The sweet milk is set at about 90° F. with sufficient rennet to coagulate it in twenty to thirty minutes. The curd is cut comparatively fine and is stirred while being heated slowly to a temperature of 110°. It is cooked much firmer than Limburg and not so firm as Emmental.

When cooked the curd is dipped into wooden hoops lined with cloth. The cheeses are pressed in rotation for a few minutes at a time, one press being used for a number of cheeses. After pressing, the cheeses are wrapped in bark for a couple of weeks, or until they are firm enough to require no support. They are cured in a moist cellar at a comparatively low temperature, as it is not desired to have eyes develop. The cheese when ready for market has a diameter of 7 inches and weighs from 9 to 15 pounds. It ripens in about twelve months and will keep for three or four years. It has a soft, buttery consistency and can be spread on bread for eating.

BERGQUARA.

This is a Swedish cheese resembling Gouda. It was known in Sweden in the eighteenth century.

BLEU.

The names Pâté Bleu and Fromage Bleu are applied to several kinds of hard rennet cheese made from cow's milk in imitation of Roquefort cheese in the southeastern part of France. Owing to the mottled, marbled, or veined appearance they are also designated Fromage Persillé. Among these are Gex, Sassenage, and Septmoncel. This name is also applied locally to several more or less distinct kinds made in the regions of the Auvergne and Aubrac mountains and designated Bleu d'Auvergne, Cantal, Guiole or Laguiole, and Saint Flour. Other cheeses of this order mentioned as made in France are Queyras, Champoléon, Sarraz, and Journiac.

BOUDANNE.

This is a French cheese made from cow's milk. The milk, either whole or skimmed, is heated to about 85° F., sufficient rennet is added to secure coagulation in one hour, and the curd is cut to the size of peas, stirred, and heated to 100° or above. After standing for ten to fifteen minutes the curd is pressed by hand and put into molds 8 inches in diameter and 3 inches in height. The cheeses are drained, turned frequently, salted, and ripened for two to three months.

BOX (FIRM).

This cheese, known in different localities where made as Hohenburg, Mondsee, and Weihenstephan, is made from whole cow's milk and is a rather firm rennet cheese. The flavor is said to be mild but piquant. The milk is heated to 90° to 93° F. in a kettle, is colored with saffron, and set with sufficient rennet to curdle it in twenty to twenty-five minutes. The curd is cut up as fine as peas and the contents of the kettle are heated very slowly to a temperature of 105°, being stirred meanwhile. The fire is then removed and the curd allowed to settle for five minutes, when the whey is dipped off. The curd is then dipped into a cloth and from this is scooped into hoops. Light pressure is applied and in fifteen minutes the cheese is turned, and the turning is repeated frequently for several hours. The cheese is kept in a well-ventilated room at 60° for three to five days, after which it is taken to the cellar. It is salted by rubbing or sprinkling salt on the surface. Ripening requires from two to three months. The cheese weighs from 1 to 4 pounds, and is undoubtedly similar to the Brick cheese of the United States.

BOX (SOFT).

This is a rennet cheese made from partially skimmed cow's milk and known locally as Schachtelkäse. It is a rather unimportant variety produced in Württemberg in a small locality called Hohenheim, a name which the cheese often takes.

In making this cheese the skimmed evening's milk is mixed with the whole morning's milk, or a part of the milk is skimmed with a centrifuge and is mixed with an equal volume of whole milk. The cheese is made in a copper kettle. The milk is warmed to 110° F., colored with saffron, and rennet added. It is allowed to stand for one to one and one-half hours before cutting. The curd is cut into rather coarse particles, after which it is allowed to stand for a few minutes, when the whey is dipped off, and for every 200 pounds of milk used a small handful of caraway seed is added. The curd is then dipped into hoops 6½ inches in height and the same in diameter. It remains in these hoops for ten hours and is frequently turned, after which it is transferred to a wooden hoop only one-half as high, where it remains for twelve hours. The cheese is then sprinkled with salt and put in the ripening cellar, where it remains about three months.

A soft rennet cheese known as Fromage de Boîte is made in the mountains of Doubs, France, in the fall. It resembles Pont l'Évêque.

BRA.

This cheese is made by nomads in the region of Bra in Piedmont, Italy. It is a hard rennet cheese weighing about 12 pounds. The milk, which is partly skimmed, is heated to about 90° F., and sufficient rennet is added to coagulate it in thirty to forty minutes. The curd is cut to the size of rice grains and the whey removed after about one-half of an hour. The curd is put into a form about 12 inches in diameter and 3 inches in height and subjected to pressure for twelve to twenty-four hours. It is salted by immersion in brine and also by sprinkling salt on the surface. The cheese is then ripened.

BRAND.

This is a German hand cheese weighing about one-third of a pound, made from sour-milk curd cooked at a little higher temperature than ordinarily practiced. The curd is salted and allowed to ferment one day. It is then mixed with butter, pressed into shape and dried, and finally placed in kegs to ripen, during which process it is moistened occasionally with beer.

BRICK.

The exact derivation of this name is not known. It may have been adopted because of the shape, or because of the fact that bricks are used almost exclusively for weighting down the press. Brick cheese is a rennet cheese made from unskimmed cow's milk, and is purely an American product. In characteristics it is about halfway between Limburg and Emmental. It has a strong, sweetish taste, a sort of elastic texture, and many small round eyes or holes. It is made about 10 by 6 by 3 inches in size. There are many factories making this product, especially in southern Wisconsin.

Perfectly sweet milk is set in a vat at 86° F. with sufficient rennet to coagulate it in twenty to thirty minutes. The curd is cut with Cheddar curd knives, and is then heated to 110° to 120° and stirred constantly. The cooking is continued until the curd has become firm enough so that a handful squeezed together will fall apart when released. The curd is then dipped into the mold, which is a heavy rectangular box without a bottom and with slits sawed in the sides to allow drainage. The mold is set on the draining table. a follower is put on the curd, and 1 or 2 bricks are used on each cheese for pressure. The cheeses are allowed to remain in the molds for twenty-four hours, when they are removed, rubbed all over with salt, and piled three deep. The salting is done each day for three days, after which the cheese is taken to the ripening cellar, which should have a temperature of from 60° to 65° and be comparatively moist. Ripening requires two months.

BRICKBAT.

This is a rennet cheese made as early as the eighteenth century in Wiltshire, England. It is made from fresh milk, to which a small portion of cream has been added. The milk is set at about 90° F. and allowed to stand two hours before the curd is disturbed. The curd is cut coarse, dipped into wooden forms, and light pressure applied. The cheese is said to be fit for consumption for one year after being made.

BRIE.

This is a soft rennet cheese made from cow's milk. The cheese varies in size and also in quality, depending on whether whole or partly skimmed milk is used. The method of manufacture closely resembles that of Camembert.

This cheese has been made in France for several centuries. Mention was made of it as early as 1407. It is made throughout France, but more extensively in the Department of Seine et Marne, in which it doubtless originated. This Department contains Meaux, Coulommiers, and Melun, places noted for their manufacture of Brie cheese, though often under local names. More or less successful imitations of this cheese are made in other countries. It was estimated that 7,000,000 pounds of Brie cheese was sold in Paris during 1900. The export trade is also very important.

The milk used is usually perfectly fresh. It is not uncommon, however, to mix the evening's milk, when kept cool over night, with the morning's milk. Some artificial coloring matter is added to the milk, which is then set with rennet at a temperature of 80° to 85° F. After standing undisturbed for about two hours the curd is dipped into forms or hoops, of which there are three sizes in common use. The largest size is about 15 inches in diameter, the medium size about 12 inches in diameter, and the smallest size about 6 inches in diameter. These vary in height from 2 to 3 inches. After draining for twenty-four hours without pressure being applied, the hoops are removed and the surface of the cheese is sprinkled with salt. Charcoal is sometimes mixed with the salt used. The cheese is then transferred to the first curing room, which is kept dry and well ventilated. After remaining in this room for about eight days, the cheese becomes covered with mold. It is then transferred to the second curing room or cellar, which is usually very dark, imperfectly ventilated, and has a temperature of about 60° F. The cheese remains here for from two to four weeks or until the consistency and odor indicate that it is sufficiently ripened. The red coloration which the surface of the cheese finally acquires has been attributed to an organism designated *Bacillus firmatatis*. The ripening is due to one or more species of molds which occur on the surface and produce enzyms which in turn cause a gradual and progressive breaking down of the casein from the exterior toward the center. The interior of a ripened cheese varies in consistency from waxy to semiliquid and has a very pronounced odor and a sharp characteristic taste.

BRINSEN.

This cheese, known locally as Laudoch, Zips, Liptau, Siebenbürgen, Neusohl, Altsohl, and Klencz, is made in the Carpathian Mountains of Silesia from sheep's milk, or a mixture of sheep's and goat's milk.

The cheese is made in small lots, only 2 to 4 gallons of milk being used at one time. This is put into a kettle when fresh and sufficient rennet is added with the milk at a temperature of from 75° to 85° F. to secure coagulation in fifteen minutes. The curd is broken up and the whey dipped and the curd is placed in a linen sack and allowed to drain for twenty-four hours. It is then cut into pieces and placed on a board, where with frequent turnings it is allowed to remain until it commences to get smeary, which requires about eight days. The pieces are then laid one on top of another in a vessel holding from 40 to 60 pounds, where they remain for twenty-four hours, after which they are removed, the rind cut away, and the curd or partially cured cheese broken up in another vessel. After ten hours salt is stirred in and the curd run through a mill which cuts it very fine, when it is packed in a tub with beech shavings.

BROCCIO.

This is a sour-milk cheese made from sheep's milk in Corsica. It is sometimes mixed with sugar and rum and made into small cakes. It is similar to Ziger.

BURGUNDY.

This cheese, known in France as Fromage de Bourgogne, is described as a soft, white, loaf-shaped cheese weighing about 4 pounds.

CACIOCAVALLO.

This is a somewhat peculiar kind of cheese made from either whole or partly skimmed cow's milk. Various explanations have been made as to the origin of the name, which means literally horse cheese. One explanation offered is that the cheese was originally made in the region of Monte Cavallo, and another is that the imprint of a horse's head was made in each cheese as the trade-mark of the original manufacturer. The original home of this cheese was southern Italy, but it is now made extensively in northern Italy as well. The history of the cheese dates back several centuries.

The temperature of the coagulation of the milk with rennet varies greatly but is usually from 90° to 95° F. The time allowed for coagulation is also variable, being usually about one-half hour. The curd is cut very finely and sometimes allowed to ferment for twenty-four hours, when it is heated by means of very hot water, or more commonly hot whey, and subsequently worked by hand until all the whey is expressed and the curd becomes homogeneous and capable of being drawn out into long threads. It is then molded into any desired shape and salted by immersion in brine for about two days. The cheeses are suspended in pairs from the ceiling and lightly smoked. The surface may be rubbed with olive oil or butter. They are kept in a cool, dry room until sold. As seen on the market they vary much in size and shape. On an average they weigh about 3 pounds. The most common shape is that resembling a beet, a constriction near the top being due to the string which is tied around the cheese for the purpose of hanging it up. This cheese is sometimes eaten while comparatively fresh, but is more frequently kept for months and then grated and used for flavoring soups and as an addition to macaroni and similar foods. A small quantity is imported into the United States.

CAERPHILLY.

This is a hard rennet cheese made in Wales from unskimmed cow's milk. The milk is set very sweet at a temperature of 85° F. with enough rennet to coagulate it in one hour. The curd is cut in ½-inch cubes and stirred for one hour without further heating. It is then put in cloths and subjected to light pressure for an hour and is again broken up fine and put to press, where it remains with daily changing for three days. During this time one-half ounce salt to each pound of curd is rubbed on the surface. Each cheese weighs about 8 pounds. The cheese requires about three weeks for ripening, at a temperature of 65 to 70°.

CAMBRIDGE.

This is a soft rennet English cheese made from cow's milk. Milk is set at 90° F. and rennet added. At the end of one hour the curd is dipped into molds without cutting and allowed to stand for thirty hours, when it is ready for eating.

CAMEMBERT.

This is a soft rennet cheese made from cow's milk. A typical cheese is about 4½ inches in diameter and 1¼ inches thick and is usually found on the market in this country wrapped in paper and inclosed in a wooden box of the same shape. The cheese usually has a rind about one-eighth of an inch in thickness which is composed of molds and dried cheese. The interior is yellowish in color and waxy, creamy, or almost fluid in consistency, depending largely upon the degree of ripeness.

Camembert cheese is said to have originated in 1791 in the locality from which it derives its name in the Department of Orne, in the northwestern part of France. The industry extended soon into Calvados, and these two Departments are still the principal seat of the industry. Cheese of the same type, however, is made in other parts of France and also in other countries; among these are Compiègne, Contentin, Pavillon, Soumaintrain, and Thury-en-Valois. Very successful results have been obtained at the Storrs Agricultural Experiment Station in Connecticut.

Camembert cheese is made from whole fresh milk or from milk which has been partly skimmed. The evening's milk may be skimmed and mixed with the fresh morning's milk. The temperature of setting is about 80° to 85° F., and the quantity of rennet added for this purpose is sufficient to secure the desired degree of firmness in about two hours. The curd is then transferred, usually with as little breaking up as possible, to perforated tin forms or hoops about 4½ inches in diameter and the same in height. These rest upon rush mats which permit free drainage. The filling of the forms may be done at two or three times separated by short intervals allowed for the curd to settle. Each form holds the equivalent in curd of about 2 quarts of milk. After draining for about eighteen hours, and preferably in a room having a uniform temperature of 65° to 70°, the cheese is turned. This is repeated frequently for about two days, when the cheese is removed from the forms and salted on the outside. Two or three days later the cheese is transferred to a well-ventilated room where the ripening process begins. The cheese remains here for fifteen to twenty days, during which time it is turned very frequently and the surface becomes covered with molds, which gradually produce a breaking down of the casein. It is then taken to the curing cellar, where the ripening process is completed in about three weeks, when it is packed and marketed.

CANQUILLOTE.

This is a skim-milk cheese made in the eastern part of France. It is also known locally as Fromagère, and Tempête. The milk is allowed to coagulate spontaneously, after which it is heated gently and the whey drawn off. The curd is pressed in order to remove as much of the whey as possible, crumbled fine, and fermented at a temperature of about 70° F. for two or three days, during which time it is stirred frequently. When the cheese has acquired its characteristic taste it is melted with the addition of water, salt, eggs, and butter and put into molds of various kinds.

CANTAL.

This is a hard rennet cheese made from cow's milk more or less skimmed. Its manufacture is extensive in the Department of Cantal, France. It is also known as Auvergne or Auvergne Blue on account of its being manufactured in the region of the Auvergne Mountains. Locally the cheese is commonly known as Fourme. The cheese is doubtless a very old variety and the method of manufacture has remained quite primitive. The milk, usually fresh but sometimes several hours old, is set with rennet at a temperature of about 85° F., the time allowed for coagulation being about thirty minutes. The curd is then cut very finely and the whey dipped off. The curd is subjected to pressure in order to remove as much of the whey as possible, and is allowed to ferment for twenty-four hours, which process is considered very important. The curd is then broken up by hand or by machinery and salted at the rate of 2.5 to 3 per cent. When thoroughly kneaded it is put into hoops about 14 inches in diameter. Pressure is applied for about two days, during which time it is turned very frequently. The cheese is next transferred to the curing cellar, where it remains for six weeks to six months. The yield of cheese is usually 10 to 11 per cent of the weight of the milk. A ripened cheese weighs from 40 to 120 pounds.

CHAMPOLÉON.

Champoléon, or Queyras, is a hard rennet cheese made from skim milk in the Department of Hautes-Alpes, France.

CHAOURCE.

This is a soft whole-milk rennet cheese resembling Camembert and deriving its name from the village of Chaource, in the Department of Aube, France. It is about 4 inches in diameter and 3 inches thick.

CHASCHÖL DE CHASCHOSIS.

This cheese is made in the Canton of Grisons, Switzerland. It is a hard rennet cheese made from skimmed cow's milk. The cheeses are 18 to 22 inches in diameter, 3 to 4 inches high, and weigh from 22 to 40 pounds.

CHEDDAR.

This cheese is so named from the village of Cheddar in Somersetshire, England, where it was first made. It is a comparatively old cheese, though the genuine Cheddar process as it is now known is not old. Cheddar cheese is an exceedingly popular variety, being much used as a food product in America and England. It is probably the most important of all cheeses as regards the quantity made annually. The term Cheddar as used at the present time applies usually to a process of making rather than to any particular shape of cheese. The name, however, is occasionally used to designate a certain size of cheese 14 to 16 inches in diameter, and weighing from 60 to 100 pounds. Cheese made by the Cheddar process has, however, many different shapes with distinguishing names, such as Flats, which have the same diameter as the Cheddar size but weigh only 30 to 40 pounds; Daisies, which are 12 inches in diameter and weigh 20 pounds; Young Americas, which are 8 inches in diameter and weigh 8 to 12 pounds; Long Horns, which are 5 inches in diameter and weigh 12 pounds; and Squares, which are of various sizes and usually 3 to 4 inches thick. The cheese may be white or colored yellow, and it may be almost fresh or thoroughly ripened and broken down. It is made from sweet cow's milk, which may be skimmed, partly skimmed, or unskimmed. When made from unskimmed milk the cheese is called "full cream;" when otherwise, it is called "part skim" or "skim."

The milk, morning's and evening's mixed, is set at 85° F. with sufficient rennet to coagulate to the proper point in from twenty-five to forty minutes. At the time of setting the milk should have an acidity of about 0.18 to 0.20 per cent. Color may or may not be used. The curd is cut when it breaks evenly before the finger. The cutting is done with curd knives. These knives are made up of blades set about one-third of an inch apart in frames. In one frame the knives are set perpendicularly and in the other horizontally. When well cut the curd is in uniform cubes of about one-third of an inch.

After cutting the curd is heated slowly and with continued stirring until it reaches a temperature of from 96° to 108°. With the use of mechanical agitators, as is the common practice, the curd should be heated about 4 degrees higher than when stirring is done by hand. After heating the stirring is continued intermittently until the curd is sufficiently firm. This is determined by squeezing a handful, which should fall apart immediately on being released. The whey is then drawn. At the same time the acid should have reached about 0.20 per cent or one-fourth of an inch on the hot iron, which latter is determined by measuring the length of strings when the curd is touched to a hot iron. The curd is then matted about 4 inches deep, sometimes in the bottom of the vat, sometimes on racks covered with a coarse linen cloth. After it has remained here long enough to stick together it is cut into rectangular pieces easy to handle, which are turned frequently and finally piled two to four deep; in the meanwhile the temperature of the curd is kept at about 90°. When the curd has broken down until it has the smooth feeling of velvet, which requires from one to three hours, it is milled by means of a machine, which cuts it into pieces the size of a finger. It is then stirred on the bottom of the vat until whey ceases to run, which requires from one-half to one and one-half hours, when it is salted at the rate of 2 to 2½ pounds of salt to 100 pounds of milk. It is then ready to put in press. The curd is put into tinned iron hoops of the proper size, which are lined with cheese-cloth bandages. The hoops are put in presses and great pressure is applied by means of screws. The next morning the cheese is removed from the hoops and put on shelves in a curing room. Formerly the cheese was kept in a curing room as long as six months, but at the present time it is covered with a coat of paraffin and put in cold storage when three to twelve days of age. There is a growing demand on the part of consumers for mild cheese, and consequently ripening must be carried on at a temperature below 50°.

An important point in the process of manufacturing Cheddar cheese is the development of the desired amount of acid. A maximum quantity in the whey that can be developed without injuring the texture of the cheese is aimed at, and the proper breaking down of the curd before milling and salting is attributed to the acid. It is very probable that too much weight has been placed on the desirability of a maximum development of acid, and that practically as good cheese can be produced without the high acid.

CHESHIRE.

This cheese is one of the oldest and most popular of the English varieties. It is a rennet cheese made from unskimmed cow's milk, and is named for Chester County, England, where it is largely produced. It is made in cylindrical shape from 14 to 16 inches in diameter, and weighs 50 to 70 pounds. In making this cheese sufficient annatto is used to give the product a very high color. The process of manufacture varies in detail in different sections. Perfectly sweet milk, night's and morning's mixed, is set at a temperature of from 75° to 90° F. The curd is cut in one hour, usually with an instrument in which knives are set in a frame to cut cubes 1 to 1½ inches square. This is pushed down through the curd and finally worked back and forth at an angle. This is continued until the particles of curd are the size of peas, which requires about one hour. The curd is then allowed to settle and mat on the bottom of the vat for about an hour, when it is rolled up to one end, weighted down, and the whey drawn after the desired degree of acidity has been obtained. The curd is cut in pieces the right size to handle and is piled on racks. It is then run through a curd mill, salted at the rate of 3 pounds to 1,000 pounds of milk, and put into a hoop having a number of holes in the side through which skewers can be thrust into the cheese to promote drainage. The cheese in the hoop is put in a heated wooden box called an ovèn, and sometimes light pressure is applied, the pressure increasing gradually until it reaches about 1 ton. The curing cellar or room is about 60° to 65°. From eight to ten months is required for thorough ripening.

CHESHIRE-STILTON.

This is a combination of the Cheshire and Stilton varieties of cheese in which the general characteristics of size and shape and manufacture of the Cheshire is retained, and a growth of the mold peculiar to Stilton is secured. The mold is secured by keeping out each day a small portion of curd and mixing it with some curd in which the mold is growing well.

CHIAVARI.

This is a sour-milk cheese made in the region of Chiavari, Italy, from whole cows' milk. It is also known as Cacio Romano. A hard rennet cheese made in the same region is also known by this name.

COMMISSION.

This cheese is made in Holland and resembles Edam in the process of manufacture, but it has a slightly different shape, being flattened at the ends. It is said to be made from whole cow's milk.

COTHERSTONE.

This is a rennet cow's-milk cheese made in Yorkshire, England, and resembles the well known Stilton cheese of that country. It is a local product manufactured only on a small scale. It has also been known as Yorkshire-Stilton.

COOKED.

This kind of cheese is so called because the curd is heated to the melting point in its manufacture. It is made from fresh curd prepared by breaking up and heating the curd of sour clabbered milk. When cooled sufficiently this curd is placed in a receptacle and allowed to stand for three or four days until it has become colored throughout. It is then put into a kettle over a fire; salt, milk, and usually caraway seed are added, and the whole is stirred vigorously until it becomes of the consistency of thick molasses, or until it strings when a spoon is withdrawn. The mass can then be put into molds until it becomes cold, or placed in a vessel for keeping. It gets hard with cooling and will retain the shape of the mold.

Cooked cheese, made in northern Germany, is called Topfen, and a similar product made in Sardinia is called Freisa, and Paneddas. The same kind of cheese made in Belgium is called Belgian cooked cheese. Similar kinds are made in other countries.

COTTAGE.

This is a sour-milk cheese made extensively in this country, where it is often called Dutch cheese, and Smear-case. It is manufactured usually in a very small way, but occasionally it is made in large factories. Skim milk is allowed to sour and the curd is then broken up and held at a temperature of about 100° F. for three to four hours, or until it has become sufficiently firm. The whey is then drained off and the curd placed under slight pressure for a time. The curd is either consumed immediately or is packed in tubs and placed in cold storage. It is prepared for eating by moistening with either milk or cream. Sometimes it is made up into shapes and wrapped in tin foil. No ripening is ever allowed.

COULOMMIERS.

This is a small-sized Brie cheese 5 to 6 inches in diameter and 1 inch in thickness, and weighing about 1 pound. It is made in the region of Coulommiers, France.

CREAM.

Genuine cream cheese is made from a rich cream thickened by souring, or from sweet cream thickened with rennet. This is put in a cloth and allowed to drain, the cloth being changed several times during the draining, which requires about four days. It is then placed on a board covered with a cloth, sprinkled with salt, and turned occasionally. It is ready for consumption in from five to ten days.

Another variety of cream cheese is made from cream with a low content of fat (12 to 15 per cent). The cream is curdled with rennet, broken up to allow a part of the whey to escape, and is then mixed and worked into almost a paste. This is then molded into pieces weighing 2 to 4 ounces, which are wrapped in tin foil and placed on the market without curing. It is a very mild and a very rich cheese and is manufactured on an extensive scale by a few large factories in the United States.

A so-called double-cream cheese, known in France as Fromage Double Crème, is made by coagulating a mixture of milk and cream and putting this into a cloth and allowing it to drain thoroughly, when it is salted, kneaded, and molded into any desired shape. It is eaten fresh. The Gervais is a cheese of this kind.

A French cream cheese, Fromage à la Crème, is prepared by mixing sweet cream with well-ripened sour-milk curd or rennet curd. Another French cream cheese, which contains considerable salt as a preservative, is known as Demi-sel. There are in addition several cream cheeses having specific names, such as Philadelphia cream.

CREUSE.

This is a skim-milk farm cheese made in the Department of the same name in France. Coagulation is secured either by the addition of a small quantity of rennet or by heating the sour milk. When set with rennet the period required is usually twelve hours. The curd is put into earthenware molds about 7 inches in diameter and 5 to 6 inches in height, the bottom and sides being perforated. After draining for several days the cheese is removed from the molds, salted, and turned frequently. It becomes in time very dry and hard and may be preserved for a year or longer. The cheese is also ripened by placing in tightly closed receptacles lined with straw, in which case it becomes yellow and soft and acquires a very pronounced taste.

CRISTALINNA.

This a hard rennet cheese made from cow's milk in the Canton of Graubünden, Switzerland.

DAMEN.

This is a soft uncured rennet cheese made from cow's milk in Hungary and is much in demand in the markets of Vienna. It is sometimes known as Gloire des Montagnes.

DANISH EXPORT.

This cheese is made in some of the creameries of Denmark to furnish an outlet for the skim milk and the buttermilk. In the process of manufacture as high as 15 per cent of fresh buttermilk is added to the skim milk. The mixture is set at 98° F. with sufficient rennet to coagulate in twenty-five minutes. The curd is carefully and evenly cut, stirred for a few minutes, dipped into forms having rounded bottoms, kneaded, pressed down, and finally covered with a board upon which a weight is placed. Twelve hours later the cheeses are placed in a brine tank for twenty-four hours, when they are taken out and covered with salt for a short time. They are then transferred to the ripening room where the temperature is about 55° and are turned and wiped with a cloth every day for five weeks. The cheeses are cylindrical in shape and are small and flat.

DERBYSHIRE.

This is a hard rennet cheese made from whole cow's milk in Derbyshire, England. It is cylindrical in shape and about the size of the Cheshire, though often smaller. It is made usually in farm dairies, and because of this fact the size varies with the size of the herd. The quality also varies to such an extent that very few really good cheeses can be found. Night's milk in which the development of acid has been prevented as much as possible is mixed with the morning's milk and the whole is set at a temperature of 80° F. The setting period is one hour and the curd is allowed to become very firm before cutting. The curd is cut to the size of a pea and after being allowed to settle is piled in the center of the vat, where after the whey is removed it is subjected to light pressure. The curd is cut and again piled and heavier pressure applied. This is repeated until the curd reaches a certain degree of firmness, when it is run through a mill and salted at the rate of 1 pound of salt to 1,000 pounds of milk. It is then put in a press for one hour, when it is removed and the surface of the cheese scalded for one minute in water heated to 150°. It is put back in the press for five hours, the pressure applied being gradually increased, when it is salted on the surface and again pressed. The pressing continues for three days, the cheese being salted each day. The curing room is kept preferably at 60°, and the time required for curing is from three to four months.

A cheese called Gloucester made in the county of Gloucester, England, is said to be identical with Derbyshire cheese. Double Gloucester is identical with single Gloucester in all respects but size. It is twice as thick as a single Gloucester, hence the name. Wiltshire, Leicestershire, and Warwickshire cheeses belong to the Derbyshire type.

DEVONSHIRE CREAM.

In making this cheese the cream is allowed to rise for several hours, when the milk with the layer of cream is scalded. It is then set away for a short time in order that the layer of cream may harden. The cream is then put into small molds and placed upon straw mats to drain. After becoming hard enough to retain its shape it is ready for market.

DORSET.

Dorset, or Blue Dorset, is a cheese resembling in character and method of manufacture the better known Stilton. It is named from Dorsetshire, England, in which it is made.

DOTTER.

This cheese is said to have been made by G. Leuchs, in Nürnberg, by mixing the yolk of eggs with skim milk and making this mixture into cheese in the usual way.

DRY.

This cheese, known also as Sperrkäse and Trockenkäse, is made in the eastern part of the Bavarian Alps and in the Tyrol, in the small dairies of those localities. It is an extremely simple product made for home consumption, and is made only in the winter season, when the milk can not be profitably used for other purposes. As soon as the milk is skimmed it is put into a large kettle which can be swung over a fire. Here it is kept warm until it is thoroughly thickened from souring. It is then broken up and cooked quite firm. A small quantity of salt and sometimes some caraway seed are added and the curd is put into forms of various sizes. It is then placed in a drying room, where it becomes very hard, when it is ready for eating.

DUEL.

This is a soft cured rennet cheese made from cow's milk. It is an Austrian product, 2 by 2 by 1 inches in size.

DUNLOP.

This was formerly the national cheese of Scotland, but it has been almost superseded by the Cheddar, which it resembled.

EDAM.

This is a hard rennet cheese produced in Holland; it is also known as Katzenkopf, Tête de Maure, and Manbollen. The best of the product is made of unskimmed cow's milk, but much of it at the present time is made from milk which has had at least one-half of the fat removed. The cheeses are round and are colored deep red on the surface or wrapped in tin foil.

The perfectly fresh milk is set at 90° to 95° F. Color is added and sufficient rennet is used to coagulate the milk in fifteen minutes. The curd is cut and after a very short stirring is allowed to settle to the bottom, when the whey is dipped off. The curd is gathered in a pile and pressure is applied for a short time to expel the whey. Care is taken in the meanwhile that the curd does not get below 82° or above 90°. The curd is then ready for the press. Sometimes wooden molds are used, but the best are made of iron. An attempt is made to put just sufficient curd into the mold to make a perfect sphere when pressed. When the mold is half full a little salt is added. When the mold is full, it is pressed lightly until the cheese will hold its form, when it is taken out and immersed in water for two minutes at 125°. The cheese is then put in the press, where it remains for twelve hours. It is then removed from the mold and placed in another form resembling the mold but without a cover, and having a hole leading from the bottom. The cheese is salted by rubbing salt on the surface. Sometimes it is kept in a salt bath for a day before putting salt on the surface. Following the salting, the cheese is washed in hot whey, and the surface is scraped smooth. It is then taken to the ripening cellar, which should have a temperature of between 50° and 70°. Here it is turned daily for a time and finally twice a week. In the meanwhile it is occasionally moistened with cold water or fresh beer. When the cheese is one month old it is washed in water at 70° for twenty minutes and then placed in the sun to dry, after which it is rubbed with linseed oil. Before shipping the cheese is colored, usually red, but for some markets it is colored yellow with annatto. This coloring is done with a watery solution of litmus and Berlin red, or with carmine. A considerable quantity of this cheese is imported into the United States. At the present time some Edam cheeses are inclosed in air-tight tins for export.

ELBING.

This is a West Prussian hard rennet cheese made from cow's milk which, during the winter, is partly skimmed but at other times left whole. It is known also as Werderkäse, and Niederungskäse. Enough rennet is added to the milk at a temperature of 80° F. to coagulate it in from fifteen to thirty minutes. The curd is cut and cooked to 100°, salted in the granular state, and pressed for twelve hours. A cheese is 10 to 20 inches in diameter and 3 to 4 inches in thickness. Ripening requires about one month at a temperature of 75°.

EMMENTAL.

This is a hard rennet cheese made from unskimmed cow's milk, and has a mild, somewhat sweetish flavor. It is characterized by holes or eyes which develop to about the size of a penny in typical cheeses and are situated from 1 to 3 inches apart. Cheese of the same kind made in the United States is known as Domestic Swiss, and that made in the region of Lake Constance is called Algau Emmental. Other local names are Bellunese, Formaggio Dolce, Fontine d'Aosta, and Thraanen.

Emmental cheese originated in the Canton of Emmental, Switzerland. It is a very old variety. In the middle of the fifteenth century a cheese probably of this type was manufactured in the Canton of Emmental. In the middle of the seventeenth century the industry was well developed and genuine Emmental cheese was being exported. In 1722 its manufacture under the name of Gruyère is recorded in France, two cooperative societies having been organized for this purpose.

Emmental cheese is now manufactured in every civilized country. In the United States there are many factories, located principally in Wisconsin, New York, and Ohio. In Switzerland the greater part of the milk produced is made into this product, and large districts in France and northern Italy are devoted to its manufacture. The best of the product made in Switzerland is exported, about 5,000,000 pounds coming to the United States annually. The imported cheese sells in this country at about 25 cents a pound wholesale, and the domestic cheese sells at about 14 cents. Practically as good cheese can be manufactured in the United States as in Switzerland, but prejudice, combined with the fact that much of the domestic product is sold as imported, has held the price at a low level.

There is a slight difference in manipulation of the milk in making Emmental cheese in this country as compared with Switzerland. In the latter country the evening's and morning's milk are made up together, while in the United States it is popularly believed that the evening's milk must be made into cheese immediately after milking, as is done with the morning's milk.

In making the cheese in Switzerland the evening's milk is skimmed; the fresh morning's milk is heated to 108° to 110° F. and the cream from the evening's milk is added and well stirred in. The cooled evening's milk with a little saffron is then added and the whole is mixed. The milk is then brought to a temperature of 90° in summer and 95° in winter and sufficient rennet is added to coagulate the milk in thirty to forty minutes. The whole process is carried through in a huge copper kettle holding 300 gallons of milk. The rennet used is the calf's stomach soaked for twenty-four hours in whey. When the milk has thickened to almost the desired point for cutting, which is practically the same as for ordinary American or Cheddar cheese, the thin surface layer is scooped off and turned bottom side up. This is supposed to aid in incorporating the layer of cream with the cheese. The curd is then cut very coarse by means of a so-called harp. The cheese maker with a wooden scoop in each hand then draws the mass of curd toward him, that lying on the bottom of the kettle being brought to the surface. At this point the cheese maker and an assistant commence stirring the curd with the harp, a breaker having first been fitted to the inside of the kettle to interrupt the current of the whey and curd. The harps are given a circular motion and cut the curd very fine—about the size of wheat kernels or smaller.

After this stage is reached heating is commenced. In Switzerland all of the heating until recently was done over an open fire, the kettle being swung on a large crane, and most of the factories have the same method at the present time. In this country the same method was followed in the early days of the industry, but at the present time inclosed fireplaces into which the kettle can be swung and doors closed to retain the heat are largely employed. This takes away much of the discomfort of the operation. In a few instances the kettles are set in cement and an iron car containing the fire is run under it. The more modern factories employ steam, and this appears to be the most satisfactory way. When the heating is begun the contents of the kettle are brought rapidly to the desired temperature, which may be from 126° to 140°, the higher temperature often being necessary to get the curd sufficiently firm. The stirring in the meanwhile continues for about one hour, with slight interruptions near the end of the process when the curd has become so firm that it will not mat together. The end of the cooking is determined by the firmness of the curd, which is judged by matting a small cake with pressure by the hands and noting the ease with which this cake breaks when held by the edge.

When the curd is sufficiently firm the contents of the kettle are rotated rapidly and allowed to come to a standstill as the momentum is lost. This brings all the curd into a cone-shaped pile in the center of the kettle. One edge of a heavy linen cloth resembling burlap is wrapped around a piece of hoop iron and by this means the cloth is slipped under the pile of curd. The mass of curd is then raised from the whey by means of a rope and pulley and lowered into a cheese hoop on the draining table. These hoops are 4 to 6 inches deep and vary greatly in diameter. The cloth is folded over the cheese, a large follower is put on top, and the press is allowed to come down on the cheese. The press is usually a log swung at one end and operated by a double lever. Pressure is continued for the first time just long enough for the curd mass to retain its shape. The hoop is then removed, the cheese turned over, and a dry cloth substituted. The cheese is allowed to remain in the press about twenty-four hours, during which time it is turned and a dry cloth substituted several times (six or more).

At the end of the pressing the curd should be a homogeneous mass without holes. The cheese is then removed to the salting board, covered with a layer of salt, and turned occasionally. In a day or two it is put in the salting tank in a brine strong enough to float an egg; it remains here at the discretion of the cheese maker for one to four days. Often no brine tank is used with Emmental cheese.

The cheese is then taken to the curing cellar. In the best factories two or more cellars with different temperatures are available and the cheeses are placed in them according to the way the cheese maker thinks their development requires. If it appears that the cheese may develop too fast and have too many and too large eyes, the cheese is placed in a cool cellar; if the reverse is true, a warm cellar is selected. The cellars vary in temperature from 55° to 65°, though in extreme cases 70° or a little higher may be used. While the cheeses are in the ripening cellar, which in Switzerland may be six to ten months or longer, and in the United States three to six months, they should be turned and washed every other day for the first two or three months and at longer intervals subsequently, and at the same time a little coarse salt is sprinkled on the surface. In a few hours this salt has dissolved and the brine is spread over the surface with a long-handled brush.

The cheeses are very large, about 6 inches in thickness and sometimes as much as 4 feet in diameter, and weigh from 60 to 220 pounds. In shipping, a number of them are placed in a tub which may contain 1,000 pounds of cheese. Sometimes Emmental cheese is made up in the form of blocks instead of like millstones. The blocks are about 28 inches long and 8 inches square in the other dimensions.

ENGADINE.

This is made in the Canton of Graubünden, Switzerland, and is a rennet cheese made from unskimmed cow's milk.

ENGLISH DAIRY.

This name is applied to a very hard cheese, made in the same general way as Cheddar, but cooked much more. This cheese has been made mostly in the United States. It is used for culinary purposes.

ÉPOISSE.

This is a soft rennet cheese made from whole or partly skimmed milk in the Department of Côte d'Or, France.

ERVY.

This is a soft whole-milk rennet cheese resembling Camembert and deriving its name from the village of Ervy, in the Department of Aube, France. A cheese is about 7 inches in diameter, 2½ inches thick, and weighs about 4 pounds.

FARM.

This cheese, made in France, and known variously as Fromage à la Pie, Mou, Maigre, and Ferme, is essentially the same as our Cottage cheese. The method of making is very simple. When the skimmed milk has become curdled the whey is poured off and the curd kneaded and molded into various sizes and shapes. Draining is sometimes hastened by placing a board and weight upon the curd. Salt and sometimes sweet cream are added. The cheese is consumed usually on the farm where made either while fresh or after it has undergone fermentation.

FILLED.

Filled cheese is the name applied to cheese from which the butterfat has been removed and foreign fats added. The foreign fat is added by stirring it violently in the milk and setting with sufficient rennet to coagulate quickly. The rest of the manufacture is the same as for Cheddar cheese. Filled cheese was very extensively manufactured in the United States for a number of years, but State and Federal laws have made this no longer practical. Many of the European varieties of cheese are counterfeited or adulterated in the same manner.

FLOWER.

This cheese is so named because it is made with the addition of the petals of various kinds of flowers, such as roses and marigolds. It is a soft-cured rennet cheese made in England from whole cow's milk.

FORMAGELLE.

This is a small soft ripened rennet cheese made from cow's milk in the northwestern part of Italy.

FORMAGGINI.

This name is applied to several kinds of small Italian cheeses. The kind designated Formaggini di Lecco is a small cylindrical dessert cheese weighing about 2 ounces, made in the region of Lecco, in Lombardy. It is consumed while fresh and sweet and at all stages of ripening until it becomes very piquant. Sometimes salt, pepper, sugar, and cinnamon are mixed with this cheese, and occasionally oil and vinegar are added. The method of manufacture is not essentially different from that of other soft cheeses. Cow's milk is used with the addition at times of some goat's milk. Rennet is added to the warmed milk, which is then allowed to stand for twenty-four hours at a temperature of about 55° F. The curd, with as little breaking up as possible, is allowed to drain for three to four hours, when it is salted and put into cylindrical molds about 1¼ inches in diameter and 2 inches high.

FROMAGE FORT.

Several kinds of cooked cheese prepared in France are known by this name. In the Department of Ain, Fromage Fort is prepared by melting well-drained skim-milk curd, putting the melted mass into a cloth, and subjecting it to pressure and afterward burying it in dry ashes in order to remove as much of the whey as possible. The mass is then grated fine and allowed to ferment for eight to ten days, after which milk, butter, salt, pepper, wine, etc., are added to it, and the mixture is allowed to undergo further fermentation.

Canquillote, Cancoillotte, or Fromagère, prepared in the eastern part of France, is a cheese of this kind, as is also the Fondue, or cooked cheese, of Lorraine.

GAMMELOST.

Gammelost is made in Norway from skimmed sour milk. The milk is cooked or warmed in a kettle and allowed to stand for one hour while the precipitated casein gathers at the bottom. This is taken up in a cloth and the whole is put into a form where light pressure is applied. The cheese still in the cloth in the form is put in the hot whey for an hour, when it is again placed under pressure for a short period. It is put in a warm place and turned daily. At the end of fourteen days it is packed in a chest with wet straw. The cheeses vary in weight from 24 to 65 pounds.

GAUTRAIS.

This is a cylindrical cheese weighing about 5 pounds and very closely resembling Port du Salut. It is made in the Department of Mayenne, France.

GAVOT.

This cheese is made from cow's, sheep's, or goat's milk in the Department of Hautes-Alpes, France.

GEHEIMRATH.

This is a cheese made in small quantities in Holland. It resembles a small Gouda cheese in quality and process of manufacture. It is colored a deep yellow.

GÉROMÉ.

This is a soft rennet cheese made in the mountainous regions of the Vosges, France. The name is a corruption of Gérardmer, a village in the region where the cheese has been made for at least fifty years. The variety is very similar to Münster, but not so well known.

Cow's milk is used almost exclusively, though at times a little goat's milk is added. The fresh milk is set with rennet at a temperature of about 80° to 90° F. In about one-half hour after adding the rennet the curd is cut into rather large cubes and allowed to stand for about one hour when the whey is dipped off. The curd is then put into cylindrical forms or hoops 6 to 7 inches in diameter. Formerly these were made of wood, one being placed upon another, making a total height of 14 to 15 inches. They are now being made also of tin and in various sizes. The cheeses are turned after 6 hours and again after 12 hours. During the next two or three days they are turned twice daily, the hoops being changed each time. A room temperature between 60° and 70° is desired during this process. The cheeses are then salted, the amount of salt used being from 3 to 3.5 per cent of the weight of the cheese.

The cheeses are then placed in a well-ventilated room for several days and when sufficiently dry are transferred to the curing cellar. Here they are turned frequently and worked with warm salt water to prevent the growth of molds. Ripening requires from six weeks to four months, depending upon the size of the cheeses, which vary in weight from one-half pound to 5 pounds or more. Anise is sometimes incorporated with the curd before putting into the forms. Such cheese when old often has a greenish appearance.

GERVAIS.

This is a French cheese made from a mixture of whole milk and cream. The mixture is set with rennet at about 65° F., the time required being about 12 hours. The curd is then inclosed in cloth and hung up to drain. When sufficiently dry it is salted and pressed into molds. The molds are soon removed and the cheese is wrapped in paraffin paper. The cheese is usually consumed while fresh, but may be kept for several days.

GEX.

This is a hard rennet cheese made from cow's milk. It belongs to the class of blue or marbled cheese known in France as Fromage Persillé, which includes Sassenage, Septmoncel, and several other kinds resembling Roquefort. It is made principally in the southeastern part of France and derives its name from the town of Gex in the Department of Ain, where the cheese has been made for at least sixty years. There has been little tendency for the industry to extend to other regions than that in which it originated, and even here it is said to be diminishing.

Rennet is added to the fresh milk as soon as possible after milking. The time allowed for coagulation is one and one-half to two hours. The curd is then broken up and stirred until the mass is in a semiliquid condition, when it is allowed to stand for about ten minutes. After the curd has settled to the bottom of the vat the whey is drained off. The curd is then worked by hand, salted lightly, and put into hoops about 12 inches in diameter and 5 inches in height. In about one hour the cheese is turned and a disk and weight placed upon it. The turning is repeated three or four times a day, the hoops being removed at the end of the first day. After salting, the cheese is taken to the curing room, where it soon acquires a bluish appearance, due to the development of a penicillium. This mold is not introduced into the interior of the cheese during making by means of mottled bread, as is the case with Roquefort cheese. The ripening process, which requires from three to four months, is completed in cellars or natural caves. A ripened cheese weighs from 14 to 15 pounds.

GISLEV.

This is a hard rennet cheese made in Denmark from skimmed cow's milk.

GLUMSE.

This cheese is made from sour skimmed milk in western Prussia. The thickened milk is placed over a slow fire at about 105° F. and is cooked as long as any whey is expelled. The cooking may be done by pouring hot water into the milk. After cooking, the curd is removed from the whey with a perforated dipper and is allowed to drain in a hair sieve. Milk or cream is added to the cheese just before eating. This is evidently a cottage cheese.

GOAT'S MILK.

There are a large number of goat's-milk cheeses, many of which are not designated by local names. In France some of these are known by the names Chevret or Chevrotin, in Italy as Formaggio di Capra, and in German-speaking countries as Ziegenkäse or Gaiskäsli. Among those in France to which local names have been attached are Gratairon, Lamothe, and Poitiers.

The Gaiskäsli is a soft cheese made in certain parts of Germany and Switzerland. The milk is set with sufficient rennet to coagulate it in about 40 minutes. The curd is then broken up, stirred, and dipped into cylindrical molds about 3 inches in diameter. The mold is filled sufficiently to make a cheese 1½ to 2 inches thick and weighing one-half pound. The mold is set on a straw mat which allows the whey to drain freely, and salt is sprinkled on the surface. In two days the cheese is turned and the other surface is salted. The cheese requires about three weeks to ripen and is said to have a very pleasant flavor.

A kind of cheese is made in Norway by drying goat's milk by boiling, fresh milk or cream sometimes being added during the process.

GORGONZOLA.

This variety, known also as Stracchino di Gorgonzola, is a rennet Italian cheese made from whole cow's milk. The name is taken from the village of Gorgonzola, near Milan, but very little of this cheese is now made in that immediate locality. The interior of the cheese is mottled or veined with a penicillium much like Roquefort, and for this reason the cheese has been grouped with the Roquefort and Stilton varieties. As seen upon the markets in this country, the surface of the cheese is covered with a thin coat resembling clay, said to be prepared by mixing barite or gypsum, lard or tallow, and coloring matter. The cheeses are cylindrical in shape, being about 12 inches in diameter and 6 inches in height, and as marketed are wrapped in paper and packed with straw in wicker baskets

The manufacture of Gorgonzola cheese is an important industry in Lombardy, where formerly it was carried on principally during the months of September and October, but with the establishment of curing cellars in the Alps, especially near Lecco, the manufacture is no longer confined to this season.

The milk used in making this cheese is warmed to a temperature of about 75° F. and coagulated rapidly with rennet, the time required being usually from fifteen to twenty minutes. The curd is then cut very finely and inclosed in a cloth and drained, after which it is put into hoops 12 inches in diameter and 10 inches high. It was formerly the custom to allow the curd from the evening's milk to drain over night and to mix it with the fresh warm curd from the morning's milk prepared in the same way. The curd from the evening's milk and that from the morning's milk, crumbled very fine, were put into hoops in layers with moldy bread crumbs interspersed between the layers. The cheese is turned frequently for four or five days, the cloths being changed occasionally, and is salted from the outside, the process requiring about two weeks.

It is then transferred to the curing rooms, where a low temperature is usually maintained. At an early stage in the process of ripening the cheese is usually punched with an instrument about 6 inches long tapering from a sharp point to a diameter of about one-eighth inch at the base. About 150 holes are made in each cheese. This favors the development of the penicillium throughout the interior of the cheese. Well-made cheese may be kept for a year or longer. In the region where made, much of the cheese is consumed while in a fresh condition.

GOUDA.

This is a Holland cheese made from whole or partly skimmed cow's milk. It is round and weighs 10 to 45 pounds. The milk, to which coloring matter has been added, is set at 91° F. with sufficient rennet to coagulate it in fifteen minutes. The curd is cut or broken with a wooden scoop, a harp, or an American cheese knife. It is allowed to stand for a minute and the whey is dipped off. Hot whey or hot water is poured on the mass of curd until the whole has reached a temperature of 104° to 110°. When the curd squeaks or whistles when it is crushed between the teeth, the whey or water is dipped off and the curd is stirred and piled where it will drain well. The curd is then thoroughly kneaded and sometimes lightly salted. After salting, the curd is put into round molds and placed in a press, where it remains for twenty-four hours with increasing pressure. The cheese is then salted either by immersion in brine or by rubbing salt on the surface. The salting continues for four to eight days. After salting, the cheese is washed with hot whey. It is then transferred to the ripening cellar, where it is turned daily for several days and finally once a week until ripened. It is ready for consumption in six to eight months. When the cheese is a few days old it is washed with water and colored with saffron. Some of this cheese is shipped to the United States. As seen in this country each cheese is covered with an animal tissue, said to be a bladder.

GOURNAY.

This is a soft rennet cheese which derives its name from the village of Gournay in the Department of Seine-Inférieure, France, where it is made. It is about 3 inches in diameter and three-fourths inch thick.

GOYA.

This cheese is manufactured in the Province of Corrientes, in the Argentine Republic. Either whole or partly skimmed milk is used. It is heated to a temperature of 75° to 85° F. and coagulated with rennet in fifteen to thirty minutes. The curd is cut and put into sacks to drain, after which it is put into molds.

GRANULAR CURD.

This cheese resembles the genuine Cheddar process cheese in all points excepting that it is not matted and milled. As soon as the curd is cooked firm enough it is salted and pressed. Because no acid is developed between cooking and pressing, a little more acid may be allowed to develop before drawing the whey, and the curd should be cooked firmer.

GRAY.

This is a sour skim-milk product of the Tyrol. When the milk is thickened the curd is brought to a proper firmness by light heating, and is then dipped into a cheese cloth, care being taken that the flocculent matter at the bottom of the kettle is thoroughly mixed with the rest of the curd in order to insure an even product. The curd is put under a press for ten minutes, when it is broken up by hand or in a mill and salt and pepper are added. The curd is then put into forms or hoops, and to insure the proper ripening a little well-ripened grated gray cheese is added, or bread crumbs with the characteristic mold growth are mixed with the curd as it is put into the forms. The forms are made in various shapes and sizes and are supplied with holes to facilitate drainage. The cheese remains in the forms under pressure for twenty-four hours, and is then taken to the drying room, which has a temperature of 70° F. The length of time it should remain in the drying room is determined by the appearance of the cheese. It is then taken to the ripening cellar. The cheese when ripened has a pleasant taste and a gray appearance through the entire mass.

GRUYÈRE.

This name is applied to Emmental cheese manufactured in France, the name originating from the Swiss village of Gruyère. The cheese was first mentioned in 1722, when two societies were reported to have been organized for its manufacture. The Gruyère cheese is made in three different qualities—whole milk, partly skimmed, and skimmed. It is usually made from partly skimmed milk, and this is supposed to distinguish it from Emmental, which is supposed to be made from whole milk. The manufacture of Gruyère cheese is an extensive industry in France, about 50,000,000 pounds having been manufactured annually the latter part of the last century.

GÜSSING.

This is an Austrian skim-milk cheese weighing from 4 to 8 pounds. It resembles very much the brick cheese of the United States and is made in practically the same way.

HAND.

Hand cheese is so named because it was molded originally into its final shape by hand. It is a sour-milk cheese, very popular among German races, and manufactured in many countries.

The process of making varies in different localities, but in general is about as follows: The skimmed milk is mixed with buttermilk and put into a tinned vessel where it is held at a favorable temperature for souring. When thick the curd is broken up by stirring and heated to 120° F. The cooking is continued for about three hours and for the first hour of this time is stirred thoroughly. After cooking the whey is drained off and the curd is put in a mold for cooling. It is then ground fine in a curd mill and salt is incorporated, and for some kinds caraway seed is added. The curd is then pressed into the desired shapes and sizes. The small cheeses are dried in a warm room and then transferred to the curing cellar, where they are kept on shelves until the ripening on the surface has commenced, when they are packed in boxes. The cheese has a very sharp, pungent odor and taste, which to most people unaccustomed to it are very disagreeable.

There are many local names for hand cheeses, among which are the following: Thuringia caraway cheese; Ihlefeld, made in Mecklenburg; Livlander, made in Russia; Olmützer Bierkäse; Dresdener Bierkäse; Satz, made in Saxony; Tyrol sour cheese; Berliner Kuhkäse, and Alt Kuhkäse.

HARZ.

This is a hand cheese made in different sizes. It is 1½ to 2½ inches in diameter and ½ to ¾ inch in thickness and weighs one-fourth pound. It is identical in manufacture with hand cheese.

HAY.

This cheese, known as Fromage de Foin, is a skim-milk variety made in the Department of Seine-Inférieure, France. The cheese derives its name from the fact that it is ripened on as freshly cut hay as possible, which gives a characteristic aroma to the cheese. The cheese in some respects resembles a poor grade of Livarot. It is about 10 inches in diameter and 2 to 3 inches thick.

The milk is set with rennet at a temperature of 80° to 85° F. In about one hour the curd is cut and the whey removed; the curd is then pressed to remove as much of the whey as possible, after which it is pressed by hand into molds. After draining for about two days it is put into the drying room, where it remains for about three weeks, when it is taken to the curing cellar and buried in hay. After remaining here for six weeks to three months it is ready for sale. The consumption of this variety is largely restricted to the region where it is made.

HOHENHEIM.

This is a soft cheese made in Hohenheim from partly skimmed milk. It is cylindrical in shape, 4 to 6 inches in diameter, and weighs about one-half pound.

The skimmed evening's milk is added to the morning's milk and heated in a copper kettle to 110° F. Some saffron is used for color and rennet is added. In one to one and one-half hours the curd is broken up and the whey dipped off. Caraway seed is stirred in, by which process the curd is reduced to smaller particles. It is then dipped into tin hoops having holes to allow easy draining. The curd remains in these hoops for twelve hours and an additional twelve hours on a drying board. It is then sprinkled with salt and when this is dissolved it is again salted and placed in the ripening cellar. Ripening requires three months.

HOLSTEIN HEALTH.

This is a cooked cheese made from sour skimmed milk, the local name being Holsteiner Gesundheits Käse. The milk is heated lightly and the curd is strongly pressed; it is then well mixed and put in a tin kettle. A little cream and salt are added and the whole is stirred while it is being heated to the melting temperature over a fire. It is then put into a hoop or mold which holds about one-half pound and is allowed to cool.

HOLSTEIN SKIM-MILK.

As the name indicates, this is a skim-milk cheese made in the Province of Holstein, where it is known as Holsteiner Magerkäse. Usually in the manufacture of this cheese 6 per cent of buttermilk is added to separator skim milk. A part is heated to 160° F. and the remainder is mixed with the pasteurized portion. The milk is colored with saffron, and rennet powder is used for coagulating the casein, which requires about 35 minutes. The curd is then broken up and allowed to remain in the whey for thirty minutes without stirring. A cloth is then used for lifting the curd from the whey, and 1 per cent of salt is mixed in. The curd is pressed for one-half hour, when it is turned and pressure again applied. The pressure is gradually increased from 5 pounds to 9 pounds for each pound of cheese. The cheese is transferred to the curing cellar, which has a temperature of 60°. It is here turned daily until ripened, which requires four months. Each cheese weighs from 12 to 14 pounds.

HOP.

Hop or Hopfen cheese is a German product. The ground curd is salted and allowed to ripen for three or four days, when it is mixed with fresh curd and molded into small cheeses measuring about 2½ inches in diameter and 1 inch in thickness. These are placed in a well-ventilated room and allowed to become quite dry, when they are packed in hops.

HVID GJEDEOST.

This is a goat's-milk cheese made in Norway. The milk is set at 70° F. or higher. The curd is broken up and is cooked in the usual manner. It is then pressed in forms 9 to 10 inches long, 6 inches broad, and 4 inches high. The cheese is made only for local consumption.

ILHA.

Ilha is a Portuguese word meaning island, and is applied to the cow's-milk cheeses made in the Azore Islands and imported quite extensively into Portugal. They are moderately firm cheeses measuring 10 to 12 inches in diameter and about 4 inches in thickness.

INCANESTRATO.

This name is applied to cheese made in Sicily. The mixture of evening's and morning's milk is curdled with rennet in about three-fourths of an hour. The curd is then stirred thoroughly and 2 per cent of water is added. After standing for five minutes the curd is separated from the whey, pressed by hand, and sometimes allowed to ferment for two to three days, when it is cooked in whey and then pressed and salted. Various spices are added. A kind known as Majocchino and made in the region of Messina, out of cow's, goat's, and sheep's milk, contains olive oil.

ISIGNY.

This is an American cheese originating about thirty years ago in attempts to make Camembert cheese in this country. The proper ripening for Camembert cheese was not secured and hence a distinct name was given to the product. The cheese is slightly larger than Camembert but of the same shape. The ripened product bears a close resemblance to Limburg. The process of manufacture is similar to that of Camembert. During ripening, however, the cheese is washed and rubbed occasionally to check the growth of molds on the surface.

JOCHBERG.

This cheese is made from a mixture of cow's and goat's milk in the Tyrol. The cheese weighs 45 pounds and is 20 inches in diameter and 4 inches high.

JOSEPHINE.

This is a soft cured rennet cheese made from whole cow's milk in Silesia. It is put up in small cylindrical packages.

KAJMAK.

The Turkish word Kajmak signifies cream and is used to designate a product made in Servia and sometimes known as Servian butter. This product is, however, analogous to a cream cheese. The milk is boiled and put into large shallow vessels usually made of wood, and allowed to stand for twelve hours, when the cream is removed and usually salted. The flavor varies greatly with the age of the sample and is said to be between that of a goat's-milk cheese and Roquefort.

KASCAVAL.

This is a loaf-shaped rennet cheese weighing from 4 to 6 pounds, made from sheep's milk in Bulgaria, Roumania, and Transylvania. Goat's milk is sometimes added. Considerable quantities of the cheese are exported.

KATSCHKAWALJ.

This is a sheep's-milk cheese made in Servia. The milk is curdled with rennet and the curd is drained and inclosed in tin cans which are put into boiling water. The curd is subsequently worked by hand and molded into various shapes. A cheese weighs ordinarily about 6 pounds.

KJARSGAARD.

This is a hard rennet cheese made in Denmark from skimmed cow's milk.

KLOSTER.

This is a soft ripened rennet cheese made from unskimmed cow's milk. It has a somewhat unusual shape, 1 by 1 by 4 inches, and weighs less than one-fourth pound.

KOLOS-MONOSTOR.

This is a sheep's-milk rennet cheese made in the agricultural school in Transylvania. The cheese is rectangular in shape, 8½ by 5 by 3 inches, and weighs 4 pounds.

KOPPEN.

Koppenkäse is a goat's-milk cheese made in Germany. The milk is set at 80° to 85° F., and after the whey has been dipped off the curd is put into a cup-shaped vessel which gives form to the cheese and also the name. The cheese is placed in a warm room and sprinkled with salt. It is allowed to dry for from two to three days and is then placed in the ripening room. The ripened cheese weighs from 3 to 4 ounces. It has a sharp, pungent, slightly smoky flavor.

KOSHER.

This cheese under various names is made in several countries. It is a cow's-milk rennet cheese made for the Jewish trade. The process of manufacture resembles that of Limburg. The cheese, however, is eaten fresh.

KOSHER GOUDA.

This is a cheese made especially for the Jewish trade. It is identical with a Gouda cheese in every way except in size and in having no bladder covering. It weighs from 4 to 6 pounds and is 8½ inches in diameter and 3 inches thick. It bears a stamp which identifies it to the Jewish consumer. Small quantities are imported into this country.

KRUTT.

Krutt, or Kirgischerkäse, is made by the nomadic tribes of the middle Asiatic Steppes from sour skim milk of the cow, goat, sheep, or camel. When the milk coagulates salt is added and the curd is hung up in a sack to drain, after which it is subjected to moderate pressure. The curd is then made up into small balls which are placed in the sun to dry.

KUHBACH.

This is a soft ripened rennet cheese made from whole or partly skimmed cow's milk. It is a German product, made in upper Bavaria. It is cylindrical in shape, weighs 2 pounds, and is 6 inches in diameter and 3 inches high.

LAGUIOLE.

This is a hard rennet cheese varying but little if any from Cantal and resembling Roquefort. It derives its name from the village of Laguiole in the Department of Aveyron, France. The cheese is made extensively in the mountains of Aubrac, where it is said to have been made at the time of the Roman occupation. The milk, either whole or partly skimmed, is set with rennet, the time allowed being about thirty minutes. The curd is allowed to ferment for about twenty-four hours and is then put into hoops and pressed. At least one month is required for ripening. Laguiole or Guiole cheese is considered superior to Cantal, although the two varieties are made in essentially the same way.

LANCASHIRE.

This is an English cheese named from the county in which it is made. The evening's milk is partly skimmed and is heated so that when the morning's milk is added the temperature of the whole is brought to 80° F., or slightly higher. Enough rennet is added to coagulate the milk in one hour. The curd is broken up, stirred for a short time, and pressed on the bottom of the vat by means of a heavy sieve. The whey is soon drained off and the curd is ground in a curd mill into particles the size of kernels of corn and then put into the press. Salting is done in brine in which the cheese is placed for four to six days. From the brine tank the cheese is transferred to the curing room.

LANGRES.

This is a soft rennet cheese made in the northeastern part of France. It derives its name from the village of Langres in the Department of Haute-Marne, where it is said to have been made since the time of the Merovingian kings. The perfectly fresh milk is set with rennet at a temperature of about 90° to 95° F. After standing for several hours it is put into cylindrical forms. The cheeses ripen for about two to three months. A ripened cheese weighs from 1½ to 2 pounds and is about 5 inches in diameter and 8 inches high. The cheese is consumed for the most part in the region where made.

LAPLAND.

The Laplanders make a variety of cheese from the milk of the reindeer. It resembles very much the harder varieties of the Emmental group. The cheese has a very unusual shape. It is round and flat and is so formed that a cross section would resemble a dumbbell with angular instead of round ends.

LATTICINI.

This is applied to cheeses made from the milk of buffaloes, particularly in the region of Naples, but also in other parts of Italy.

LEATHER.

Leather, Leder, or Holstein dairy cheese is made in Schleswig-Holstein, from skimmed cow's milk with an addition of from 5 to 10 per cent of buttermilk.

The milk is set at from 95° to 100° F. and requires twenty-five to thirty-five minutes for coagulation. It is then broken up with a harp or a stirring stick, and is stirred with a Danish stirrer. When the particles are reduced to the size of peas the curd is piled up on one side of the vat or kettle and allowed to stand for ten minutes. The whey is then dipped off. The curd is cut with a knife into pieces the size of the hand, put in a wooden or tin bowl, and pressed for one-half hour, when it is cut into pieces and run through a cheese mill. It is then salted, put in a cloth, and again put in the press, where the pressure is gradually increased. The cheese is turned occasionally and a fresh dry cloth supplied. After twelve hours of pressing the cheese is put into the salt bath, where it is kept forty to forty-eight hours. It is then transferred to the ripening cellar, where it is wiped with a dry cloth every day for about a week and thereafter twice a week, the ripening requiring about four months. The cured cheese has small eyes; it is made cylindrical, and is 4 to 6 inches in height and 10 to 12 inches in diameter. It weighs 15 to 25 pounds.

LEICESTER.

This is a hard rennet cheese made from whole cow's milk. It is named from a county in England where it is made. It resembles the better known Cheshire and Cheddar in every way.

Evening's and morning's milk are mixed and set at a temperature of from 76° to 84° F. The curd is allowed to set very firm, which requires ninety minutes. It is cut very carefully and allowed to settle twenty minutes, when the whey is drawn off. The curd is then gathered in a cloth, pressed, and broken up several times until a certain degree of dryness has been attained, and then salted lightly and put to press. Pressure is continued for five days, the cheese being removed and salted on the outside each day.

LEYDEN.

This is a hard rennet cheese made in Holland, where it is known also as Bergues, Delft, Komynde, Koejekaars, and Hobbe. The milk, which is either partly or entirely skimmed, is set with rennet at 72° to 75° F. It is allowed to stand for one hour, when the curd is cut and then stirred while being warmed up to 97°. The heating is done by pouring hot whey over the curd. The curd is then dipped out with a cloth and kneaded by hand. Caraway seed is added to a portion of the curd which, in filling the hoops, constitutes the middle of three layers. The cheese is then put in press. It is turned after three hours and a fresh cloth applied. The pressing continues for twenty-four hours. Salting is done on the surface daily. If the rind becomes hard it is washed in whey or water, and occasionally milk is smeared on the surface. The surface is colored with litmus in alkaline water. A ripened cheese weighs about 25 pounds and is 12 inches in diameter and 3½ to 5 inches in thickness. As seen on the American market it has a very dark-brown surface.

LIMBURG.

This is a soft rennet cheese made from cow's milk which may contain all of the fat or be partly or entirely skimmed. The best Limburg is undoubtedly made from whole milk. This cheese has a very strong and characteristic odor and taste. The cheese is about 6 by 6 by 3 inches and weighs about 2 pounds.

The most common synonyms of Limburg are Backstein and Hervé. There are, however, many local names for this kind of cheese, such as Algau, Lanark, Marianhof, Morin, St. Michels, Schützen, Tanzenberg, Carinthian, Grottenhof, Emmersdorf, Briol, and Lindenhof.

Limburg cheese originated in the province of Lüttich, Belgium, in the neighborhood of Hervé, and was marketed in Limburg, Belgium. Its manufacture has spread to Germany and Austria, where it is very popular, and to the United States, where large quantities are made, mostly in New York and Wisconsin.

Sweet milk is set without any coloring matter at a temperature of from 91° to 96° F. with sufficient rennet to coagulate the milk in about forty minutes. In foreign countries a kettle is used but in the United States an ordinary rectangular cheese vat is found to be more satisfactory. The curd is cut or broken into pieces about one-third-inch cube and is stirred for a short time without additional heating. It is then dipped into rectangular forms, 28 inches long, 5½ inches broad, and about 8 inches deep. These forms are kept on a draining board where the whey drains out freely. When the cheese has been in the forms with frequent turnings for a sufficient length of time to retain its shape it is removed to the salting table, where the surface is rubbed with salt daily. When the surface of the cheese commences to get slippery, the cheese is put in a ripening cellar having a temperature of about 60°. While in the cellar the surface of each cheese is rubbed thoroughly at frequent intervals. Ripening requires one to two months. When ripe the cheese is wrapped in paper, and then in tin foil, and put in boxes each containing about 50 cheeses.

No Limburg is imported into this country at the present time, contrary to the popular belief. The type of cheese is made so cheaply and of such good quality in this country that the foreign make has been crowded out of the market.

LIPTAU.

This cheese is made in the Provinces of Liptau, Saros, and Arva, in Austria, from sheep's milk. Condiments, especially red pepper, are usually added. It is rather greasy and has a sharp taste. The details of manufacture are the same as for Brinsen cheese.

LIVAROT.

This is a soft rennet cheese made from cow's milk more or less skimmed. It derives its name from the village of Livarot in the Department of Calvados, France, where the industry is centralized. This cheese has the advantage over Camembert made in the same region in that it may be manufactured and consumed during the warm months.

The milk is set with rennet at a temperature of 95° to 104° F. After one and one-half to two hours the curd is cut and placed on a rush mat or a cloth and allowed to drain for about fifteen minutes, during which time it is crumbled as finely as possible. It is then put into tin hoops or forms 6 inches in diameter and the same in height. The cheeses are turned very frequently until they become firm, when they are salted and left on the draining board for four or five days. At this stage they are sometimes sold as white cheese, but more often they are transferred to a well-ventilated room for fifteen to twenty days and then to the curing cellar, which is kept very tightly closed. By thus retaining the ammonia and other products the cheese acquires a strong, piquant taste. During ripening the cheeses are turned two or three times a week and occasionally wiped with a cloth moistened with salt water. After ripening for ten to twelve days they are wrapped with the leaves of *Typha latifolia*, commonly called laiche. In three to five months they are colored with annatto and marketed.

LORRAINE.

This is a small sour-milk hand cheese made in Lorraine, Germany, and regarded as a delicacy in that country. It is seasoned with pepper, salt, and pistachio nuts, and is eaten in a comparatively fresh state. The cheeses are made in sizes of about 2 ounces and sell for a very high price—at the rate of about 50 cents a pound.

LÜNEBERG.

This cheese is made in the small valleys of the Voralberg Mountains in the western part of Austria. The art of cheese making in this locality was imported from Switzerland, and the copper kettle and characteristic presses are used. Saffron is used for coloring, and the milk is warmed in the copper kettle to 87° to 90° F., at which temperature the rennet is added, enough being used to coagulate the milk in twenty to thirty minutes. The curd is cut into pieces the size of hazelnuts and is cooked with stirring to a temperature of 122°. The curd is dipped into cloths which are put into wooden forms and light pressure is applied. The curd remains in the press for twenty-four hours, during which time it is turned occasionally and a dry cloth supplied. The cheese is then taken to the cellar and is salted on the surface. In the cellar it is rubbed and washed occasionally. When ripe it is said to be about midway in type between Emmental and Limburg.

MACONNAIS.

This is a French goat's-milk cheese, 2 inches square by 1½ inches thick.

MACQUELINE.

This is a soft rennet cheese of the Camembert type, 4 inches in diameter and 1½ inches thick, made from whole or partly skimmed milk in the region of Senlis, in the Department of Oise, France. The milk is set with rennet at a temperature of about 80° F. and allowed to stand for five hours, when the curd is put into hoops. After twenty-four hours the hoops are removed and the cheese is salted and taken to the curing room, where it remains for twenty days or more. A cheese weighs about one-fourth of a pound and requires about 2 liters of milk in its manufacture. The cheese sells at a lower price than Camembert, made in the same region.

MAIKÄSE.

This is a cheese resembling Gouda. It is made in Holland in the early summer, is softer than the regular Gouda, and hence can be marketed at an earlier period.

MAINZ HAND.

This is a typical hand cheese sometimes called Pimp. The milk is treated in the usual way, and the curd after cooling is thoroughly kneaded by hand, the thoroughness of this manipulation influencing the quality of the cheese. The curd is then pressed by hand into flat cakes and allowed to dry for a week. They are then packed in a jar or keg and placed in a cellar for ripening. This requires from six to eight weeks.

MALAKOFF.

This is another form of Neufchâtel cheese about 2 inches in diameter and one-half of an inch in thickness. It may be consumed either while fresh or after ripening.

MANUR.

This cheese is made in Servia from either sheep's or cow's milk. The milk is first heated to the boiling temperature and then cooled until the fingers can be held in it. A mixture of buttermilk and fresh whey with rennet is added. The curd is lifted from the whey in a cloth and allowed to drain, when it is kneaded like bread, lightly salted, and dried.

MAQUÉE.

This is a soft rennet brick-shaped cheese made from cow's milk in Belgium. It is known where made as Fromage Mou.

MÄRKISCH HAND.

This cheese is similar to a hand cheese. The milk is treated in the same way as in hand cheese up to the salting. The curd is then put in a linen sack and heavy pressure is applied. The mass is then cut into oblong pieces and allowed to dry and cure as regular hand cheese.

MAROILLES.

This is a soft rennet cheese of the Pont l'Évêque type made from whole or partly skimmed cow's milk in the Departments of Aisne and Nord, France. There are several kinds varying in size, shape, and details of manufacture, of which the Tuile de Flandre and Larron are best known. The cheese as made at Maroilles is about 6 inches square and 2 inches thick; that made at Saint Aubin 5 inches square and 3 inches thick. The Larron is about 2½ inches square and 1½ inches thick, and weighs about 6 ounces. The Tuile de Flandre is about twice as large. The Dauphin is semilunar in shape and contains herbs. A pear-shaped form designated Boulette may be made in part from buttermilk.

The best cheese is made from fresh whole milk, although the most of it is made from milk partly or entirely skimmed. The temperature of setting with rennet is about 75° F. and the time allowed from one to four hours. The curd is drained for one to two hours in a box having a perforated bottom, and is then put into square forms or hoops 5 to 6 inches on a side and 3 to 4 inches high. The cheese is turned frequently until firm and then salted on all six faces and taken to the curing cellar where it is washed frequently with salt water to prevent the growth of molds. Ripening requires three to five months. Defective cheeses are said to be common.

MASCARPONE.

This is an Italian cream cheese about 2 inches in diameter and 2½ inches in height. The cream is heated to about 194° F. and dilute acetic or tartaric acid is added. The mixture is stirred and drained through cloth and then put into molds. It is eaten in a fresh condition.

MECKLENBURG SKIM.

This is a rennet cheese made from skim milk and named from the province in which it is made. The milk is placed in a copper kettle and warmed with steam. Saffron is added for coloring and sufficient rennet is used to coagulate the milk in 30 minutes. The curd is broken up into particles the size of peas. The temperature is raised to 92° F. in 12 minutes. The curd is then removed from the kettle by means of a cloth and put into a hoop and pressure applied. This is increased gradually until it reaches fifteen times the weight of the cheese in twenty-four hours. The cheese is then placed in a drying room held at 70° until a rind is formed. As much salt is then sprinkled on the surface as can be absorbed. In the meanwhile the cheese is taken from the drying room and placed in the regular curing room, which has a temperature of 60° and a relative humidity of 85 to 95 per cent.

MIGNOT.

This is a soft rennet cheese either cylindrical or cubical in form. It has been made in the Department of Calvados, France, for over one hundred years and resembles Pont l'Évêque and Livarot. There are two types of this cheese, designated white and passé; the first, a fresh cheese, is made during the period from April to September, and the second, a ripened cheese, is made during the remainder of the year.

MONTASIO.

This cheese originated in the part of Carinthia, in Austria, called Friaul, where the annual product is now valued at $600,000. At the present time it is made not only in Carinthia, but in the neighboring provinces and in Italy.

The milk, either whole or partly skimmed, and consisting usually of a mixture of cow's and goat's milk, is heated in a kettle to 95° F. and sufficient rennet is added to coagulate it in thirty to forty minutes. It is then cut very carefully to the size of peas and heated gradually to a temperature of 120°. When the desired temperature is reached, which is usually in about one-half hour, heating is stopped and the stirring continued for thirty to forty minutes. Some of the whey is dipped from the kettle and the curd is removed by means of a cloth. The cheese is pressed for twenty-four hours, during which time it is turned frequently. The salting requires usually about one month, the total amount applied varying from 2½ to 3 per cent of the weight of the pressed cheese. After salting, the cheese is taken to a well-ventilated room and allowed to dry. In this room the cheese is turned frequently and rubbed in order to free it from molds. When dry it is scraped carefully and taken to the curing cellar. The cheese is here rubbed frequently with a coarse cloth, and when the rind has become firm and does not show the presence of mold, olive oil is usually applied. Sometimes the rind is colored black by means of soot.

The fresh cheese is almost white. The old cheese becomes yellow, granular, and has a sharp taste and characteristic odor. It is usually eaten when three to twelve months of age, but may be kept much longer and then grated.

MONTAVONER.

This is a sour-milk cheese made in Austria. During the process of manufacture dried herbs (*Achillea moschata* and *A. atrata*) are added.

MONT CENIS.

This is a hard rennet cheese resembling the imitation Roquefort varieties like Gex and Septmoncel and made in the region of Mont Cenis, in the southeastern part of France. The milk used is usually a mixture of cow's, sheep's, and goat's. The evening's milk is usually skimmed and added to that of the morning. Primitive methods of cheese making are employed. The milk is set with rennet at a temperature of about 85° F. The curd is then cut and allowed to drain for twenty-four hours, when fresh curd is thoroughly mixed with it. The mixture is then put into molds and moderate pressure applied. After turning frequently for several days and salting it is transferred to the curing cellar, where it is turned frequently, washed with salt water to check the growth of molds on the surface, and allowed to ripen for three to four months. The ripening is due mainly to a penicillium which is sometimes incorporated in the curd by means of moldy bread. A ripened cheese is about 18 inches in diameter, 6 to 8 inches in height, and weighs about 25 pounds.

MONT D'OR.

This is a soft rennet cheese of the Pont l'Évêque type formerly made from goat's milk but now made almost exclusively from cow's milk. Sometimes a small amount of goat's milk is added to the cow's milk.

It derives its name from Mont d'Or, near Lyons, in the Department of Rhône, France, where it is said to have been made for over three centuries. At the present time it is made not only in Rhône and neighboring Departments but in the other parts of France, especially Eure and Oise.

Whole or partly skimmed milk is set with rennet at a temperature of 90° to 100° F. The curd, in from one-half hour to two hours after the addition of the rennet to the milk and with or without cutting, is put into circular forms or hoops about 4½ inches in diameter and 3 inches high. These rest upon a draining board covered with straw. After about one hour the cheese is turned, and frequently thereafter until firm. A disk with a light weight is sometimes placed upon each cheese in order to hasten the removal of the whey. The cheese is salted on the surface. Much of it is sold in a fresh condition. It is also ripened for about one week in summer and two to three weeks in winter, during which time it is turned frequently and washed with salt water to prevent the growth of molds.

MONTHLÉRY.

This is a soft rennet cheese made from cow's milk in Seine-et-Oise, France. A large cheese is about 2 inches thick and 14 inches in diameter and weighs about 5½ pounds. There is also a smaller sized cheese which weighs about 3 pounds. Either whole milk or partly skimmed milk is used. Rennet is added to the milk at ordinary temperatures, and the curd when sufficiently firm is broken up, put into molds, and subjected to pressure. After salting the cheese is cured for eight to fifteen days in a so-called drying room and then ripened in a cellar at a temperature of about 55° F. During ripening the cheese becomes covered at first with a whitish mold and later with a blue mold in which red spots appear. It is ready for sale at the end of about one month.

MOZARINELLI.

This is a soft rennet cheese made from cow's milk in Italy.

MÜNSTER.

Münster is a rennet cheese made from unskimmed cow's milk in the western part of Germany, near the Vosges Mountains, and named from the city of Münster, near which it is made. Similar cheese made in the neighboring portion of France is called Géromé, and Münster cheese made near Colmar and Strassburg is sometimes given the names of these two cities.

The milk is set at about 90° F. with sufficient rennet to coagulate it in thirty minutes. The curd is then broken up and allowed to stand for thirty to forty-five minutes without stirring, when it is dipped with a sieve which holds back the small particles of curd and gives a slight pressure to the curd. After removing the whey the curd is scooped into forms or hoops and caraway or anise seed is usually added. The hoops are made in two parts, the lower of which is 4 inches high and 7 inches in diameter with holes in the bottom for draining, and the upper of which is of the same dimensions. The whole resembles an ordinary cheese hoop with bandages. The hoop is lined with cheese cloth. After the curd has been in the hoop for twelve hours the upper part of the hoop can be removed. The cheese is turned and the cloth removed. The cheese is now put in the upper portion of the hoop and turned frequently for four to six days. The temperature is held in the meanwhile at 68°. After salt has been rubbed on the surface daily for three days the cheese is taken to the cellar, which has a temperature of 51° to 55°, where it is allowed to ripen for two to three months. The cheese sells for about 15 cents a pound when ripe.

MYSOST.

Mysost is made from whey and is a product of Norway, Sweden, and Denmark, and to a very limited extent of the United States. It has a light-brown color, a buttery consistency, and a mild, sweetish taste.

The method of manufacture is as follows: As soon as the curd of the regular cheese is removed from the whey, the whey is strained and is put in a kettle or large pan over the fire and the albuminous material which rises to the surface is skimmed off. The whey is evaporated as rapidly as possible with constant and thorough stirring. When it has reached about one-fourth its original volume the albumin previously skimmed off is returned and stirred thoroughly to break up all possible lumps. When the whey has attained the consistency of thickened milk it is poured quickly into a wooden trough and stirred with a paddle until cool to prevent the formation of sugar crystals. This can then be molded into the desired form. In this country it is usually made into cylindrical shapes and wrapped in tin foil.

NIEHEIM.

This is a sour-milk cheese made in Westphalia and named from a city in that province. The sour milk is heated to a temperature of 100° to 120° F. The curd is collected in a cloth and allowed to stand for twenty-four hours, when it is worked until in a fine condition. The curd is made up into cakes which are put into a cellar and turned frequently for five to eight days. It is then broken up, and salt and caraway seed, and sometimes beer or milk, are added. The cheese is covered lightly with straw and finally packed in casks with hops and allowed to ripen.

NESSEL.

This is a soft-cured rennet cheese made from unskimmed cow's milk. It is an English product and is made round and very thin.

NEUFCHÂTEL.

This is a soft rennet cheese made extensively in the Department of Seine-Inférieure, France, from cow's milk either whole or skimmed. Bondon, Malakoff, Petit Carré, and Petit Suisse are essentially the same as Neufchâtel, but have slightly different shapes.

The milk, preferably fresh, is set at 85° F. with only so much rennet as is necessary to secure the desired coagulation in twenty-four hours in summer and from thirty-six to forty-eight hours in winter. The curd is then inclosed in cheese cloth and drained for twelve hours, after which it is subjected to pressure for another period of twelve hours. It is then thoroughly kneaded by hand, or in the larger factories by means of a curd mill, and pressed into tin cylinders about 2 inches in diameter and 3 inches high. The cheeses are removed soon from the molds, salted, and replaced. After draining for twenty-four hours they are transferred to the so-called drying room, where they become covered with white and later with blue molds. They are then taken to the curing cellar, where the ripening process is continued for three to four weeks. The appearance of red spots on the surface is taken as an indication that the ripening has progressed far enough. The cheeses are then wrapped in tin foil and marketed.

NEW MILK.

This cheese is made in Holland. The process of manufacture resembles that of Gouda cheese. It is made only in limited quantities at the beginning of the summer season and is eaten fresh.

NOSTRALE.

This name is applied locally to two kinds of rennet cheese made from cow's milk in the mountainous regions of northwestern Italy. The hard cheese, designated Formaggio Duro, is made during the spring while the herds are still in the valleys, and the soft cheese, Formaggio Tenero, during the summer when they are pastured in the mountains. The cheese is said to be a very old variety and the methods of manufacture to have remained primitive. A cheese designated Raschera made in the region of Mondovi is probably the same as Nostrale.

OLIVET.

This is a soft rennet cheese made from cow's milk. The manufacture of this variety originated south of Orleans, in the Department of Loiret, France. The industry is now carried on north of Orleans near Olivet, to which place the cheese doubtless owes its name. There are three forms of this cheese, designated white or summer cheese, blue or the ordinary half-ripened form, and ripened. In general the process of manufacture resembles that of Camembert. The ordinary form is made from either whole milk or partly skimmed milk. About two hours after the addition of rennet the curd is placed in a receptacle having holes in the bottom and sides and allowed to drain for twenty-four hours, when it is put into forms about 6 inches in diameter. The cheese is turned and salted the next day and about one day later is taken to the first curing room, where it is placed on shelves covered with straw. This room is kept at a temperature of about 65° F. Here the cheese becomes red in a few days and later blue. The blue color is a sign of maturity, and its appearance requires from ten to fifteen days in summer and one month in winter. The cheese is then ready for marketing. When properly cared for it may remain in good condition for several months. The form designated ripened is made in the same way until the blue color appears, when the cheese is put into the curing cellar where ripening is carried to a much further extent. Ordinarily this requires from fifteen to thirty days, but the cheese is here sometimes covered with ashes, which are believed to hasten the ripening process. The form designated white or summer cheese is made from whole milk to which cream is sometimes added. The curd is obtained in the ordinary manner and pressed into molds in which it is sold as fresh cheese, summer cheese, white cheese, or cream cheese.

OLMÜTZER QUARGEL.

This is a hand cheese made extensively in the western part of Austria. It is 1½ inches in diameter and one-third of an inch thick and contains caraway seed. It is made with 5 per cent of salt and after drying is put in salt whey for a time. It is then packed in kegs and ripened for eight to ten weeks. In all other respects the manufacture is identical with that of hand cheese.

PAGLIA.

This is a more or less successful imitation of Gorgonzola cheese, made in the Canton of Ticino, Switzerland. A cheese is 8 inches in diameter and 2 inches in thickness. The milk is set at a temperature of 100° F., the time allowed being about fifteen minutes. The curd is broken up, stirred, and put into hoops. When sufficiently drained the cheese is taken to a cool cellar and placed on straw, where fermentation is usually very rapid and marked. The process is delayed to some extent by excessive salting, which is continued for about one month. The cheese is very soft in consistency and has a pleasant aromatic flavor.

PAGO.

This is a rennet cheese made from sheep's milk in the Island of Pago, in the Province of Dalmatia, Austria. It is put up in sizes weighing from one-half to 8 pounds.

PARMESAN.

This name is in common use outside of Italy for the cheese made and known in that country for centuries as Grana, the term grana or granona referring to the granular appearance of the cheese when broken, as is necessary on account of the hardness of the cheese, which makes cutting practically impossible. There are two quite distinct kinds of this cheese, one made in Lombardy and the other in Emilia, the centers of production being separated by the River Po. Parma, situated in Emilia, has long been an important commercial center for both kinds, and to this fact the name Parmesan is due. The use of the term Parmesan, however, is sometimes restricted to the cheese made in Lombardy, the term Reggian being used to designate that made in Emilia. Italian writers refer usually to the Lombardy cheese as Cacio or Formaggio Grana Lodigiano, Lodi being an important center of trade, and to the Emilian cheese as Grana Parmigiano or Reggiano. The Lodi cheese is larger and made from a poorer quality of milk than the Reggian. The latter is colored and brings a much higher price. The following description of the process of manufacture applies equally well to both kinds.

The milk which has been skimmed to a greater or less extent is heated in copper kettles to a temperature varying according to the acidity of the milk from 90° to 100° F. The kettle is then removed from the fire, rennet added, and the kettle covered and allowed to stand for twenty minutes to one hour, when the curd is cut very fine and cooked, with stirring, to 115° to 125° for fifteen to forty-five minutes. The curd is removed from the kettle by means of a cloth and after draining for a short time is put into hoops. These are about 10 inches high and 18 inches or more in diameter and are lined with coarse cloth before filling. Pressure is then applied for twenty-four hours, the cheese being turned frequently and the cloths changed. The salting, which is begun in one to three days after removing from the press, is continued for a considerable length of time, often forty days. The cheeses are then transferred to a cool, well-ventilated room, where they may be stored for years, the surface being rubbed with oil from time to time. The exterior of the cheese is dark green or black, due to coloring matter rubbed on the surface. A greenish color in the interior has been attributed to the contamination with copper from the vessels in which the milk is allowed to stand before skimming.

The Lombardy cheese made from April to September is known locally as Sorte Maggenga and that from October to March as Sorte Vermenga. The Reggian cheese is made only in summer.

Parmesan cheese when well made may be broken and grated easily and may be kept for an indefinite number of years. It is grated and used largely for soups and with macaroni. A considerable quantity of this cheese is imported into this country and sells for a very high price.

PECORINO.

The Formaggio Pecorini are the sheep's-milk cheeses made in Italy and of which there are numerous more or less clearly defined kinds. The most common cheese of this sort is the one designated Cacio Pecorino Romano, or merely Romano. This varies considerably in size and shape. The weight may range from 2 to 25 pounds. A cheese of ordinary size is about 10 inches in diameter and 6 inches in thickness. The interior is slightly greenish in color, somewhat granular, and devoid of eyes or holes. In making Romano cheese the milk is heated to 100° F. and coagulated by rennet in fifteen minutes. The curd is cut, cooked to 120°, stirred, and put into forms and allowed to drain. Salting is done both by immersion in brine and by rubbing salt on the surface. As much as 7 to 8 per cent of salt is usually incorporated in the course of one month. This process is sometimes facilitated by punching several holes in the cheese. Ripening is usually done at a temperature of 60° to 70° and requires eight months or longer.

The Pecorino Dolce is artificially colored with annatto and subjected to considerable pressure in the process of manufacture.

Pecorino Tuscano is a smaller cheese than the Romano, measuring usually 6 inches in diameter and 2 to 4 inches in thickness and weighing 2 to 5 pounds.

Among the sheep's-milk cheeses bearing local names are the following: Ancona, Cotrone, Iglesias, Leonessa, Puglia, and Viterbo. In the manufacture of Viterbo cheese the milk is curdled by means of a wild artichoke, *Cynara scolymus*.

PFISTER.

This cheese is classed in the Emmental group though its method of manufacture differs materially. It is made from fresh skimmed cow's milk. It takes its name from Pfister Huber, in Cham, Switzerland, who evidently was the first to manufacture it.

The milk is set at 85° F. with sufficient rennet to coagulate it in thirty minutes. The curd is cut coarse and allowed to stand for fifteen minutes when the whey is dipped off. The curd is again stirred for five minutes, care being taken that the temperature does not fall below the setting point. The curd is again allowed to stand for five minutes when it is taken from the kettle in a cloth and put in a hoop, where it is pressed for twenty-four hours, being turned occasionally and dry cloths substituted. The cheese is transferred from the press to the salt bath where it remains for three days. It is then taken to a moist room having a temperature of 85°. Here it is placed on shelves and turned and salted occasionally. The cheese is ready for market at about 6 weeks of age. It is drum-shaped, like a characteristic Emmental, but not so large, weighing about 50 pounds.

PHILADELPHIA CREAM.

This is an ordinary cream cheese put up by a firm in New York State. It is 3 by 2½ by 1¼ inches in size and is wrapped in parchment paper and tin foil.

PINEAPPLE.

This cheese, which is said to have had its origin in Litchfield County, Conn., about 1845, is so named from the fruit of that name which the cheese is made to resemble in shape. It is a hard rennet cheese made from whole cow's milk. The cheese is quite hard and is rather highly colored. The early process of manufacture is the same as with Cheddar, except that it is cooked much harder. The curd is pressed in the desired shape in various sizes up to 6 pounds in weight. After pressing, the cheese is dipped for a few minutes in water at 120° F. and is then put in a net for twenty-four hours, which gives it the diamond-shaped corrugations on the surface. It requires several months to ripen and during this time the surface is rubbed with oil, which makes it very smooth and hard.

PONT L'ÉVÊQUE.

This is a soft rennet cheese made from cow's milk. Three grades are recognized, depending upon the quality of the milk used. A Pont l'Évêque cheese is about 4½ inches square and 1½ inches thick.

This cheese was made in the thirteenth century in the valley of Auge, from which it derived its earlier name Augelot, and by corruption Angelot. The principal seat of the industry at the present time is Pont l'Évêque and vicinity, in the Department of Calvados, France. The manufacture of this cheese is of considerable importance in the region designated. The milk used may be either whole milk with or without the addition of cream, a mixture of whole and skimmed milk, or milk entirely skimmed.

Coloring matter and warm or hot water are usually added to the milk before setting with rennet, which is done at a temperature of about 95° F. After standing for fifteen to thirty minutes the curd is cut, removed to a draining board for a few minutes, and then put into square forms or hoops. The cheese is turned very frequently during the first half hour and five or six times more during the remainder of the first day. It is salted the second or third day and transferred to a well-ventilated room for several days. When sufficiently dried it is taken to the curing cellar. During drying and ripening the cheeses are turned every other day and while in the cellar are washed frequently with salt water. Ripening requires usually from three to six weeks.

PORT DU SALUT.

This is a rennet cheese made from cow's milk. In many respects it is intermediate between the soft and hard varieties. The rind is firm and resistant but the interior is soft and homogeneous, though it does not become semiliquid like the interior of Brie cheese. This variety of cheese originated about 1865 in the Trappist Abbey, Port du Salut, situated about 6 miles from Laval, in the Department of Mayenne, France. While the process is to some extent kept a secret by the Trappists, very successful imitations are made outside of the monasteries in this region.

The milk, either whole or partly skimmed and preferably slightly acid, is heated to 90° to 95° F. and sufficient rennet added in order to secure the desired firmness of the curd in about thirty minutes. Coloring matter is usually added to the milk. The curd is cut very fine and in a manner similar to that followed in making Emmental cheese. This requires about twenty minutes. A part of the whey may then be removed. The curd is then stirred and may be heated or cooked to a moderate degree. The final temperature reached in cooking varies from 100° to 105°, depending upon the acidity of the milk. The time required in stirring and heating is about twenty minutes. The curd is then allowed to settle and the whey removed. After being stirred vigorously for two to four minutes, the curd is put into molds which are of two sizes, the smaller about 7 inches in diameter and the larger about 10 inches. A disk is placed on the cheese and pressure applied by means of presses for ten to twelve hours, the cheese being turned and the cloths frequently changed during this time. The next day the hoops are removed and the cheese salted. After drying for about twenty-four hours, it is transferred to the ripening cellar where it remains from five to six weeks. In this place a temperature of about 55° and a relative humidity of 85° to 90° is preferred. During ripening the cheeses are turned very frequently and washed with salt water, the frequency depending somewhat upon the rapidity with which molds develop. The cheese is often sold before the ripening process is entirely complete.

POTATO.

This cheese is made in Thuringia in the central part of Germany. In the manufacture of potato cheese, curd is made from sour cow's milk, or in some cases from renneted milk. Sometimes sheep's or goat's milk is used. The potatoes are boiled and grated or mashed. One part of the potatoes is thoroughly mixed or kneaded with two or three parts of the curd. In the better cheese three parts of potatoes is mixed with two parts of curd. During the mixing, salt is added and sometimes caraway seed. The cheese is allowed to stand for two to four days while a fermentation takes place. After this the curd is again thoroughly kneaded and placed in forms for a day. It is then dried and is sometimes covered with beer or cream. It is finally placed in tubs and allowed to ripen for fourteen days.

POTTED.

This domestic cheese is usually prepared from well-ripened Cheddar cheese by grinding the cheese very fine and incorporating with it butter, condiments, spirits, etc. It is put up in small porcelain jars and is much in demand.

PRATTIGAU.

This is made from skimmed cow's milk and is so named from the valley of Switzerland in which it is made. Its manufacture is the same as that of Limburg. Cheeses weigh from 20 to 25 pounds.

PRESTOST.

Prestost is a product of Sweden, where it is often called Saaland Pfarr. It is a rennet cheese made from fresh cow's milk and resembles Gouda. It was known in the eighteenth century. The milk is set at 90° F. and is allowed to become very firm, when it is cut coarse with a wooden knife and poured into a sieve which allows the whey to drain off. The curd is then put into a cloth and kneaded. Whisky is mixed with the curd, which is then packed in a basket, and after some salt is sprinkled on the surface it is put in the cellar. The cloth inclosing the cheese is changed daily for three days, after which the cheese is washed with whisky. A cheese is cylindrical in shape and weighs 5 to 30 pounds.

PROVIDENCE.

This cheese is about 8 inches in diameter and 1½ inches thick, and very closely resembles Port du Salut. It is made in the monastery of Bricquebec in the Department of Manche, France.

PROVOLE.

This is one of the most esteemed of the several kinds of hard rennet cheese made in central and southern Italy from cow's milk, including also that of buffaloes. The cheese is round or oval and weighs from 4 to 6 pounds. Smaller sizes weighing about 2 pounds are known as Provoloni. In many respects, including the cooking of the curd with hot water and the smoking of the cheese, Provole and Provoloni resemble Caciocavallo. Considerable amounts of this cheese are imported into the United States.

PULTOST.

Pultost, also called Knaost, is made usually from sour milk but it may be made with rennet. It is a Norwegian product and is made in private dairies in the mountains of that country. The milk is placed in a kettle and if not sour enough to coagulate on warming the acidity is increased by the addition of buttermilk. When sufficient acid has developed the milk is warmed to 113° F. The curd is broken up with a scoop and stirred to keep it from matting together while it is being heated to 140°. It is then dipped and ground up fine. Buttermilk is added and the whole is thoroughly kneaded and put into troughs, where it is covered with a cloth. It is allowed to stand for three days with occasional stirring.

QUESO DE CINCHO.

This is a sour-milk cheese made in Venezuela and known also as Queso de Palma Metida. It is exported in the form of balls 8 to 16 inches in diameter and wrapped in palm leaves.

QUESO DE HOJA.

This is a Porto Rican cheese made from fresh cow's milk. The curd is cut into blocks about 6 inches square and 2 inches thick. After part of the whey is drained off, which may require several hours, the pieces of curd are immersed in water or whey having a temperature of 150° F. This gives a tough layer to the block of curd, which is then removed to a table and pressed or stretched by the use of a broad wooden spoon or paddle. Salt is sprinkled on the surface and the piece of curd is folded and wrapped in a cloth and squeezed to force out the moisture. The finished product is about 6 inches in diameter, 1 to 2 inches thick, and has slightly rounded top and bottom surfaces. When the cheese is cut it appears to be in layers like leaves upon one another, hence the name, signifying leaf cheese.

QUESO DE MANO.

This is a sour-milk cheese resembling a hand cheese, and is made in Venezuela. It is 6 to 7 inches in diameter.

QUESO DE PRENSA.

This is a Porto Rican product, and is a hard rennet cheese made from unskimmed cow's milk. The milk is allowed to stand six hours without cooling and rennet is then added. The curd is broken by hand or with a stick, and after part of the whey is separated the curd is transferred to a table and is broken into small pieces. It is then put in wooden frames, and salt is added either as the curd goes into the frame or by sprinkling on top. Light pressure is applied, either by hand or by means of a screw. After leaving the press the cheese is placed on racks. It may be eaten fresh or allowed to stand for two to three months. The cheeses are 11 inches long, 5½ inches wide, and 3 inches thick, and weigh about 5 pounds. The name signifies pressed cheese.

QUESO DE PUNA.

This is a Porto Rican product, resembling very much the Cottage or Dutch cheese of the United States. The milk is set with rennet and the curd is thoroughly mashed or kneaded by hand, salt being added at the same time. The curd is put in a hoop 5 inches in diameter and 1½ inches deep, where it remains without pressure for two or three days, or until it will keep its form. The cheese is eaten fresh.

RABACAL.

This is a round, rather firm cheese made from the milk of sheep and goats in the vicinity of Coimbra, Portugal. A cheese is 4 to 5 inches in diameter and 1 inch thick.

RADEN.

This is a hard rennet cheese made from skim milk in Mecklenburg. The cheeses are 16 inches in diameter and 4 inches thick, and weigh 32 pounds. The process of manufacture does not differ materially from that of Emmental.

RANGIPORT.

This cheese is in every way analogous to Port du Salut. It is about 6 inches in diameter and 2½ inches thick and weighs about 2½ pounds. It is made in the Department of Seine-et-Oise, France.

RAYON.

This is a special type of Emmental cheese made largely in the Canton of Fribourg, Switzerland, for exportation to Italy, though some is now manufactured in Italy. It is made of partly skimmed milk, and the cooking is continued to a point that insures a very dry hard cheese which develops no eyes. After curing it is shipped largely to Turin, where it is placed on edge on shelves in a dry, warm cave, and the fat leaks out, leaving the cheese exceedingly dry and hard, when it is used for grating. After the drying process the cheese is called Raper.

REBBIOLA.

Rebbiola, or Robiola, is a soft cheese made principally in the Alpine districts of Italy. The process of manufacture is very simple. It is generally made from milk skimmed after twelve hours, but whole milk is sometimes used. The cheese is circular and weighs about 2 pounds. The ripening process is very rapid, requiring usually twelve to fifteen days. The milk is set at a temperature of 90° F., the time allowed being usually about one-half hour. The curd is cut fine and put into molds 8 inches in diameter and 6 inches high, the bottom being perforated. Five hours later the cheeses are removed from the molds and placed on a draining board covered with straw. After two or three days they are salted and then ripened.

REBLOCHON.

This is a soft French cheese weighing 1 to 2 pounds. It is made from fresh whole milk which is curdled with rennet at a temperature of 80° F. or above, the time allowed being about thirty minutes. The curd is cut to the size of peas, cooked to about 95°, and after the removal of the whey is put into molds about 6 inches in diameter and 2 inches in height. A weight of about 5 pounds is placed upon each cheese, which is turned frequently and salted after about twelve hours. In a moist room having a temperature of about 60° the desired degree of ripening is secured in four to five weeks. An imitation of this cheese, made in Savoy, France, is known as Brizecon.

REINDEER MILK.

In Norway and Sweden the milk of the reindeer is sometimes used for cheesemaking. Rennet is added at 100° F., and the curd is cut and dipped into a large frame, where it is pressed lightly. The mass of curd is then cut into pieces 5 by 4 by 2½ inches, which are salted on the surface and are allowed to ripen in a dry curing room.

RIESENGEBIRGE.

This is a soft rennet cheese made from goat's milk in the mountains on the northern border of Bohemia. The milk is set at about 90° F. The curd is broken up and the whey dipped off, after which the curd is put in forms, where it remains in a warm place for twenty-four hours. It is then covered with salt and after drying for three to four days is placed in the curing cellar. From each 100 pounds of milk 18 pounds of cheese is secured.

RINNEN.

This is a sour-milk cheese which was known in the eighteenth century. It is made in Pomerania from milk sufficiently acid to cause a precipitation of the curd when it is warmed to about 90° F. The cheese derives its name from the wooden trough in which it is laid to drain. The curd is broken up and heated to expel the whey. The curd is kneaded by hand and caraway seed is added. It is molded into forms and pressed. Salt is then rubbed on the outside. The cheese is dried and put in a box to ripen.

ROLL.

This is a hard rennet cheese made in England from unskimmed cow's milk. It is cylindrical in shape, 8 inches high by 9 inches in diameter. A cheese weighs 20 pounds.

ROLLOT.

This is a soft rennet cheese 2½ inches in diameter and 2 inches thick, made in the Departments of Somme and Oise, France.

ROMADOUR.

Romadour, Remoudou, or Romatur cheese is a southern Bavarian product similar to Limburg. It is 4½ by 2 by 2 inches in size and weighs 1 pound. It is said to be a little finer variety of cheese than Limburg and to sell for a slightly higher price.

ROQUEFORT.

This is a hard rennet cheese made from the milk of sheep. There are, however, numerous imitations or varieties closely resembling Roquefort, such as Gex and Septmoncel, made from cow's milk. One of the most striking characteristics of this cheese is the mottled or marbled appearance of the interior, due to the development of a penicillium, which is the principal ripening agent. The manufacture of Roquefort cheese has been carried on in the southeastern part of France for at least two centuries. The industry is particularly important in the Department of Aveyron, in which is situated the village of Roquefort, from which the cheese derives its name. It is also made in Corsica. Imitations of Roquefort cheese are made in various countries.

The evening's milk is heated to 140° to 150° F., cooled, and kept over night. After being skimmed it is mixed with the fresh morning's milk. The mixture is then set with rennet at a temperature of about 90°. In from one to two hours after the addition of rennet the curd is cut until the particles are about the size of walnuts. The whey which rises to the surface is dipped off and the curd is put into hoops which are about 8½ inches in diameter and 3½ inches in height. The hoops are filled usually in three layers, a layer of moldy bread crumbs being interspersed between the first and second and second and third layers. The bread used for this purpose is prepared from wheat and barley flour with the addition of whey and a little vinegar. It is thoroughly baked and kept in a moist place for four to six weeks, during which time it becomes permeated with a growth of the mold referred to. The crust is removed and the interior is crumbled very fine and sifted. The cheese is subjected to pressure which is gradually increased for ten to twelve hours. It is turned usually one hour after putting into hoops. At the end of about twelve hours it is wrapped in cloth and taken to the first curing room. The cloths are frequently changed during the ten to twelve days the cheese remains in this place.

Formerly the manufacture of the cheese up to this stage was carried on by the shepherds themselves, but in recent years centralized factories have been established and much of the milk is collected and there made into cheese. The cheese is then taken to the caves. These are for the most part natural caverns which exist in large numbers in the region of Roquefort. The temperature in these caves is 40° to 45°, and the air circulates very freely through them. Recently, artificial caves have been constructed and used. When the cheeses reach the caves they are salted, which serves to check the growth of the mold on the surface. One or two days later they are rubbed vigorously with cloth and are afterwards subjected to thorough scraping with knives, a process formerly done by hand, but now much more satisfactorily and economically by machinery. The salting, scraping, or brushing seems to check the development of mold on the surface. In order to favor the growth of mold in the interior, the cheese is pierced by machinery with 60 to 100 small steel needles, which process permits the free access of air. The cheese may be sold after thirty to forty days or may remain in the caves as long as five months, depending upon the degree of ripening desired. The cheese loses during ripening by scraping and evaporation as much as 25 per cent of the original weight. The weight when ripened is about 4½ to 5 pounds.

SAANEN.

This is a type of Emmental cheese made in Switzerland from cow's milk. It is sometimes known as Hartkäse, Reibkäse, and Walliskäse. First mentioned in the sixteenth century, it is still manufactured extensively at the present time and exported to a limited extent. It sells for a higher price than the regular Emmental. The process of manufacture is identical with that of Emmental except that it is cooked much dryer, takes much longer to cure, and keeps longer. The cheese weighs from 10 to 20 pounds. The eyes are few and small.

The ripening period is never less than three years and many require as long as nine years, the average being six years. The cheeses are kept to great ages, it being the custom to make a cheese at the birth of a child and eat it at the burial feast or even at the burial feast of a son of the child for whom it is made. One cheese is mentioned as being two hundred years old and is considered a great honor to the household. Many cheeses are kept until they are thirty years old.

SAGE.

This cheese is made by the ordinary Cheddar process, and may be of any of the various shapes and sizes in which that cheese is pressed. As seen when cut it has a green mottled appearance.

Formerly sage cheese was made by mixing green sage leaves with the curd before it was pressed. At the present time the flavor of sage is obtained by sage extract. To secure the green mottles, succulent green corn is cut fine and the juice is pressed out. A small portion of the milk is mixed with this juice and is set with rennet in a small vat while the bulk of the milk is set in the ordinary manner. After the curd is cut and is firm enough to be handled, the green curd from the small vat is mixed with the uncolored curd, and the process is continued as in the Cheddar process. This is a very popular variety of cheese with many consumers.

SAINT CLAUDE.

This is a small, square, goat's-milk cheese made in the region of Saint Claude, France. The milk is curdled with rennet and the curd placed in molds for six to eight hours. It is then salted and allowed to ripen, or may, however, be eaten when fresh. A cheese weighs from one-quarter to one-half pound.

SAINT BENOIT.

This is a soft rennet cheese resembling Olivet, and is made in the Department of Loiret, France. Charcoal is added to the salt which is applied to the exterior of the cheese. Ripening requires from twelve to fifteen days in summer and eighteen to twenty days in winter. A cheese is about 6 inches in diameter.

SAINT MARCELLIN.

This is a goat's-milk cheese made in the Department of Isère, France. Sheep's milk or even cow's milk may be mixed with the goat's milk. A cheese is about 3 inches in diameter and three-fourths of an inch thick and weighs about one-fourth pound.

SAINT REMY.

This is a soft rennet cheese differing but little from Pont l'Évêque. It is made in the Department of Haute-Saône, France.

SALOIO.

This is a kind of hand cheese made from skimmed cow's milk on farms in the region of Lisbon, Portugal. It has the form of a short cylinder, measures 1½ to 2 inches in diameter, and weighs about 4 ounces. A similar cheese of about the same character is made in Thomar, about 50 miles north of Lisbon.

SAP SAGO.

This cheese is made from sour skimmed cow's milk principally in Glarus, Switzerland. It is known also as Schabzieger, Glarnerkäse, Grünerkäse, and Kräuterkäse. It is claimed to have been made in the thirteenth century; the authentic history at least dates back to the fifteenth century. Sap Sago is a small, hard green cheese flavored with the leaves of a species of clover; it is shaped like a truncated cone, 4 inches high, 3 inches in diameter at the base, and 2 inches at the top. This cheese is imported to some extent into the United States under the name of Sap Sago.

The skimmed milk from which this cheese is made is not allowed to become sour enough to coagulate on heating, as it would make too hard a curd. The milk when it has reached the right acidity is heated to the boiling temperature while being stirred. Cold buttermilk is then added, as is also some whey having a high percentage of acidity. The material coagulating on the surface is skimmed off. The milk is then stirred while sufficient acid whey is added to precipitate the casein. When too little whey is used the curd is too soft, and when too much is used it is too hard. The curd is dipped with a skimmer and spread out to cool and then put in boxes and allowed to drain and ferment. The box is kept at a temperature of about 60° F. and pressure is applied by weighting with stones. Ripening is allowed to continue for three to six weeks. If the temperature of the room is too high or there is not sufficient pressure, too rapid and strong fermentation results. This curd is used for making the finished product, but the cheese is seldom finished where the curd is made. The curd is ground in a mill and every 100 pounds of cheese contains 5 pounds of salt and 25 pounds of dried *Melilotus cærulea*, an aromatic clover which is grown in the Canton of Schweiz for the purpose. The ground material is worked up into a dough and is forced into molds lined with linen cloth, and the name of the manufacturer is stamped on the large end. The mold is then emptied and refilled. The cheeses are dumped promiscuously into a large cask holding about 200 pounds. A comparatively small quantity is shipped into this country. It sells at a low price and is usually grated.

SASSENAGE.

This is a hard rennet cheese, about 12 inches in diameter and 3 inches in height, made from cow's milk to which small quantities of goat's and sheep's milk are usually added. The cheese is almost identical with that of Gex and Septmoncel. It derives its name from the village of Sassenage, near Grenoble, in the Department of Isère, France. The milk used is usually a mixture of skimmed milk and whole milk. It is set with rennet and the curd is cut and put into molds in the same manner as with the other varieties mentioned. The same is also true of the ripening process, which requires about two months.

SCANNO.

This is a soft rennet cheese made from the milk of sheep in the Apennine Mountains, in the Province of Abruzzo, Italy. It derives its name from the village of Scanno. The surface of the cheese is colored a deep black. The interior is bright yellow and has the consistency of butter.

SCARMORZE.

This is a small rennet cheese made in southern Italy from the milk of buffaloes.

SCHAMSER.

This cheese, which is also known as Rheinwald, is a rennet cheese made from skimmed cow's milk in the Canton Graubünden, Switzerland. The cheeses weigh from 40 to 45 pounds and are 18 inches in diameter and 5 inches high.

SCHLOSS.

Schlosskäse, or Castle cheese, is a Limburg cheese made in the northern part of Austria. It is a soft cured rennet cheese 4 by 2 by 2 inches in size. When ready for market it is wrapped in tin foil.

SCHOTTENGSIED.

This is a whey cheese made by the peasants of the Alps for home use.

SCHWARZENBERG.

This cheese is made in southern Bohemia and western Hungary. It is a rennet cheese made from partly skimmed cow's milk. One part of skimmed milk is added to two parts of fresh milk. In about one hour after the addition of rennet the curd is broken up and thoroughly stirred. It is then dipped into wooden forms and light pressure applied for half a day. For four or five days following the cheese is rubbed with salt and is then taken to the cellar, where it is washed daily with salt water until ripe, which requires two to three months.

SÉNECTERRE.

This is a soft rennet cheese originating at Saint Nectaire, in the Department of Puy-de-Dôme, France. It is made out of whole milk, is cylindrical in shape, and weighs about 1½ pounds.

SEPTMONCEL.

This is a hard rennet cheese made from cow's milk to which a small proportion of goat's milk is sometimes added. It resembles the Gex and Sassenage varieties very closely and its process of manufacture is almost identical with that of Roquefort. It is also known as Jura blue cheese. It derives its name from the village of Septmoncel, near Saint-Claude, in the Department of Jura, where the cheese is for the most part made. The cheese is made almost exclusively on isolated farms rather than in co-operative dairies, and the methods employed are somewhat rudimentary.

The milk, which is usually partly skimmed, is set with rennet at a temperature of about 85° F. The curd is cut and stirred after about one and one-half hours. After the curd has settled the whey is poured off. The stirring and draining are repeated several times until the curd is sufficiently firm to put into hoops. Moderate pressure is applied for a few hours. The cheese is salted at the end of twenty-four hours and thereafter daily for several days. It is then transferred to the first curing room, which is kept cool and moist. After three to four weeks it has become covered with blue mold, when it is transferred to cellars or natural caves, where the ripening is completed in from three to four weeks longer.

SERRA DA ESTRELLA.

This is the most highly prized of the several kinds of cheeses made in Portugal. The name refers to the mountainous region in which the cheese is produced. It is made for the most part from the milk of sheep, but goat's milk is often added to this or even used alone, and occasionally cow's milk is used.

The method of making this cheese is comparatively simple. The milk is warmed in a kettle with little regard to the temperature obtained, and is coagulated in most cases by means of an extract of the flowers of a kind of thistle. The time required for curdling varies from two to six hours, depending upon the amount of the extract used. The curd is broken up with a ladle or by hand, squeezed to remove most of the whey, and put into circular forms. After draining until sufficiently firm the cheeses are removed from the hoops and allowed to ripen for several weeks, during which time they are frequently washed with whey and salted on the surface. The cheeses vary much in size, the larger measuring about 10 inches in diameter and 2 inches thick, and weighing about 5 pounds. The cheese is rather soft and has a pleasant acid taste.

A similar cheese made in another part of Portugal is known as Castello Branco.

SERVIAN.

In making Servian cheese the milk is warmed in a kettle over a fire or in a tub by immersing heated stones. After the rennet is added the milk is allowed to stand one hour. The curd is then lifted in a cloth and the whey allowed to drain. It is then placed in a wooden vessel, salted, and covered successively with whey for about eight days and fresh milk for about six days.

SILESIAN.

A cheese known locally as Schlesischer Weichquarg is made from skimmed cow's milk, the process of manufacture resembling that of hand cheese. The milk is allowed to coagulate from souring and the curd is broken up and cooked at 100° F. for a short period. The curd is then put in a cloth sack and light pressure applied for twenty-four hours, after which it is kneaded by hand and salt and milk or cream are added. Flavoring substances such as onions or caraway seed are also sometimes added. The cheese is eaten fresh.

Another cheese known as Schlesischer Sauermilchkäse is also made in much the same way as hand cheese. The cheeses are kept on shelves covered with straw, and are dried by the stove in winter and in a latticework house in summer. Drying is continued until the cheese becomes very hard. The cheese is ripened in a cellar, the process requiring three to eight weeks, during which time it is washed every few days with warm water.

SIRAZ.

This is a Servian cheese made as a rule from whole milk. The milk is set at 104° F. and the curd is lifted from the whey with a cloth and pressed into cakes 4 to 6 inches in diameter and 1 inch thick. These cakes are placed in the sun to dry until the fat commences to run, when they are rubbed several times with salt until a good crust is formed. The cakes are then packed in a wooden vessel and allowed to ripen. The cut surface shows a smooth appearance without holes. It is between a hard and a soft cheese.

SLIPCOTE.

This cheese is made in Rutlandshire, England. It is a soft unripened rennet cheese, made from cow's milk. The curd is dipped into small forms and no pressure is applied. After the cheese is removed from the form the surface dries and cracks and is easily slipped off, hence the name. It is an old cheese, having been well known in the middle of the eighteenth century.

SPALEN.

This is a type of Emmental cheese, and is sometimes known as Stringer. Its origin is unknown. It is made largely in the Canton of Unterwalden, Switzerland, from sweet cow's milk, often partly skimmed. The name it derived from the vessel in which the cheeses are transported and in which five or six of them are packed. This is a small cheese for an Emmental type. Each cheese weighs from 35 to 40 pounds.

No thermometer is used in the manufacture, the temperature being judged by the feeling, and a very uneven product is the result. The process of making seems to vary much, the press consisting of a board with stones for weights, and the temperature of the cellar being poorly regulated.

SPITZ.

This is a small rennet cheese made from cow's milk. The cheese is cylindrical in shape, being 4 inches high and 1½ inches in diameter.

STEPPES.

This name is applied to a Russian cheese made from whole milk. The milk after the addition of coloring matter is heated to about 90° F. and treated with sufficient rennet to secure coagulation in forty to forty-five minutes. The curd is cut into large cubes, the whey removed slowly, and the curd still further broken up until the particles are uniformly about the size of peas. The curd is then heated gradually to 100° to 104°, the mass meanwhile being gently agitated. The stirring is kept up for some time after heating ceases until the curd becomes dry, when it is placed in molds 10 by 5½ by 7 inches. After the cheeses are removed from the molds they are turned frequently and five hours later are salted and transferred to the curing cellar, where a temperature of about 55° is maintained. During ripening the cheeses are worked occasionally with salt water and turned frequently.

STILTON.

This is a hard rennet cheese, the best of which is made from cow's milk to which a portion of cream has been added. It was first made near the village of Stilton, Huntingdonshire, England, about the middle of the eighteenth century. It is now made principally in Leicestershire and West Rutlandshire, though its manufacture has extended to other parts of England. Its manufacture has been tried, though without success, in the United States. The cheese is about 7 inches in diameter and 9 inches high, and weighs 12 to 15 pounds. It has a very characteristic wrinkled or ridged skin or rind, which is likely caused by the drying of molds and bacteria on the surface. When cut it shows blue or green portions of mold which give its characteristic piquant flavor. The price in this country is about 45 cents a pound wholesale. The cheese belongs to the same group as the Roquefort of France and the Gorgonzola of Italy.

The morning's milk is put in a tin vat and the cream from the night's milk is added, and the whole is brought to a temperature of 80° F., when the rennet is added. It is claimed by some cheese makers that the curd should be softer when broken up or cut than the curd for Cheddar cheese, while by others it is believed that it should become very firm before it is disturbed, allowing one to two hours for setting. When sufficiently firm the curd is dipped into cloths which are placed in tin strainers. After draining for one hour the cloths containing the curd are packed closely together in a large tub and allowed to remain for twelve hours, when they are again tightened and packed for eighteen hours. The curd is ground up coarse, and salt is added, 1 pound to 60 pounds of curd. The curd is then put into tin hoops 8 inches in diameter and 10 inches deep. The cheeses remain in the hoops for six days, when they are bandaged for twelve days, or until they become firm, and are then placed in the curing room at 65°. Ripened Stilton cheese is of late often ground up and put into jars holding 1 to 2½ pounds.

STRACCHINO.

This name is applied to several forms of Italian soft cheeses, the best known of which is Stracchino di Gorgonzola, which is described under the name of Gorgonzola. A square form 6 to 8 inches on a side and 1½ inches thick is known as Stracchino di Milano, Fresco, Quadro, or Quartirola. This cheese is prepared similarly to Gorgonzola but is allowed to ripen for only about two months. It is not much exported. Stracchino Crescenza is a very soft and highly colored cheese usually eaten fresh. The form is similar to that of the Quartirola. It is usually marketed in about eight days and can not be kept long.

STYRIA.

This is a cylindrical-shaped cheese made from unskimmed cow's milk in Styria, Austria.

SWEET CURD.

This is a name applied in the United States to a hard rennet cheese made from cow's milk. The name is used to distinguish it from the ordinary Cheddar or granular process, as in making Sweet Curd cheese the milk is set sweet and the cutting and cooking are done rapidly without regard to the development of acid. In making this cheese the curd is cooked very firm and is salted and put to press immediately. In all other respects the process is the same as for Cheddar, and the cheese when ripened resembles that cheese very closely.

SWISS.

Swiss or Schweitzer cheese belongs to the Emmental group of cheeses and is made usually from half-skimmed cow's milk. Its manufacture is very old. It is supposed to have originated in the Alps, but is now made in most of the surrounding countries. It is made mostly in the winter season when the price of butter is high, and only for local consumption. Its manufacture differs from real Emmental in that it is made from half-skimmed milk. The morning's milk is first heated and the skimmed evening's milk is added. The curd is cut coarser and is not cooked so firm as Emmental, which gives a softer and more quickly ripened cheese.

TAFI.

This cheese is manufactured in the Province of Tucuman, in the Argentine Republic.

TAMIÉ.

This cheese is made by the Trappists in Savoy, France. The whole milk is heated to about 80° F. and coagulated with rennet in about thirty minutes. The curd is cut fine, cooked to about 100°, stirred, and put into molds 7 inches in diameter and 4 inches in height. The cheese is pressed for six to eight hours, the cloths being changed frequently. After being salted the cheese is ripened for five to six weeks. The method of manufacture is, to a large extent, a trade secret. The Tome de Beaumont is a more or less successful imitation.

TEXEL.

This is a sheep's-milk cheese made in Holland. It was known in the seventeenth century. A cheese weighs 3 to 4 pounds and is colored green.

THENAY.

This is a soft rennet cheese resembling Camembert and Vendôme and is made in the region of Thenay in the Department of Loir-et-Cher, France. It is of comparatively recent origin and its consumption is limited practically to the region in which it is produced.

The evening's milk without being skimmed is mixed with the fresh morning's milk. The milk is set with rennet at a temperature of about 85° F. and allowed to stand for four to five hours. The curd is then broken up and put into hoops about 5 inches in diameter and 4 inches in height. After draining for about one day it is turned and salted. The cheese is then kept for about twenty days in a well-ventilated room during which time it becomes covered with molds. It is then taken to the curing cellar for about fifteen days.

TIGNARD.

This is a hard rennet cheese, resembling Gex and Sassenage, made from sheep's and goat's milk in the valley of the Tigne, in Savoy, France.

TILSIT.

This is a hard rennet cheese made mainly in East Prussia from unskimmed cow's milk. It is sometimes called Ragnit. The milk is set at 92° F. with sufficient rennet to coagulate in from fifteen to forty minutes. The curd is rather coarsely cut or broken and is cooked to 104° to 110°, being stirred meanwhile with a harp. The curd is cooked quite firm or until it can not be squeezed through between the fingers, which requires about forty minutes. It is then dipped into cylindrical forms, where it remains twenty-four hours. The cheese is then covered thickly with salt for from one to two days, when it is put into a salt bath for three to five days and then transferred to the cellar. Here it is rubbed and washed with salt water frequently, and allowed to ripen for four to six months. The cheese is 6 to 12 inches in diameter, 3 to 4½ inches in height, and weighs from 6 to 28 pounds. It resembles in general characteristics the Brick cheese of the United States.

TOPPEN.

This is a German sour-milk cheese made from skim milk and eaten while fresh. It is put up in small packages weighing about 1 ounce.

TRAPPIST.

This cheese originated with the Trappists in 1885 in the monastery of Mariastern, near Banjaluka, in Bosnia. The fresh milk is heated to about 85° F. and rennet is added. After one to one and one-half hours the curd, without being cut or stirred, is put into hoops and pressed, after which it is salted and ripened. The growth of mold is entirely prevented by frequent washing and thus the cheese ripens uniformly throughout. The ripening period of the smaller cheeses is five to six weeks in summer, but the cheese is usually shipped at the end of four to five weeks. The cheese is pale yellow in color and has a remarkably mild taste. Although this cheese is to be classed among the soft varieties, the water content is often below 45 per cent. The ripening is also more characteristic of the hard cheeses. The smallest size of the cheese made in the monastery referred to has a diameter of 6 inches, a height of 2 inches, and weighs 2 to 3 pounds. A larger size measures 9 inches in diameter, 2½ inches in height, and weighs about 10 pounds. There is also a still larger size. The cheese is exported to a large extent to Austria and Hungary, the most important centers of the trade in these regions being Gratz and Budapest. It is, however, found in all of the large cities of Austria, and the demand appears to be constantly increasing.

TRAVNIK.

This is a soft rennet cheese made usually from whole sheep's milk to which a small amount of goat's milk is added. Skimmed milk, however, is sometimes used. It is also known as Arnauten and Vlasic. This cheese originated in Albania in the northwestern part of Turkey in Europe and has been made for at least a century. In the country of origin it was known at first by the name Arnautski Sir or Arnauten cheese. At the present time it is made in Bosnia and Herzegovina, but principally in the Vlasic Plain. The center of trade in this cheese is Travnik in Bosnia.

The fresh warm milk is treated with sufficient rennet to secure coagulation in one and one-fourth to two hours and is then allowed to stand for a short time until the coagulum contracts and the whey appears on the surface. The curd is then put into woolen sacks and drained for seven to eight hours, when it is pressed into flattened balls by hand. These are dried for a short time in the open air and then packed into wooden receptacles varying in diameter from 14 to 28 inches, having a height of about 24 inches, and holding from 50 to 130 pounds of cheese. Each layer of cheese is salted and pressed so that no air spaces are left. When the receptacle is filled the whey usually shows at the surface, any excess being removed. Moderate pressure is applied to the cover placed upon the cheese. When fresh, the cheese made from whole sheep's milk has a soft consistency, a nearly white color, and a pleasant, mild taste. The cheese, however, is usually allowed to ripen for two weeks to several months. No holes should develop in the cheese.

TROUVILLE.

This is a soft rennet cheese made in the same locality as Pont l'Évêque and is of the same nature though superior in quality. Only fresh whole milk is used. The temperature of setting with rennet is 85° to 95° F. The growth of molds during ripening is prevented by frequent washing with salt water.

TROYES.

Two kinds of cheese are referred to by this name—one a washed cheese with a yellow rind, known as Ervy, and the other a cheese very closely resembling Camembert and known as Barberey. The industry is quite restricted.

TWOROG.

This is a sour-milk cheese made in Russia. The soured milk is kept in a warm place for twenty-four hours, when the whey is removed and the curd put into wooden forms and subjected to pressure. This cheese is made on a large scale by farmers and is often used in making a bread called "Notruschki."

URI.

This is a hard rennet cow's-milk cheese made in the Canton of Uri, Switzerland. It has a diameter of 8 to 12 inches, and is 8 inches high. It weighs 20 to 40 pounds.

VACHERIN.

This name is applied to two quite different kinds of cheese.

The form designated Vacherin à la Main is made in Switzerland and in Savoy, France. Whole cow's milk is set with rennet at a temperature of about 85° F., and the curd is cut very fine and put into hoops 12 inches in diameter and 5 to 6 inches high. It is salted and ripened. The rind is firm and hard but the interior is almost liquid in consistency. It is either spread on bread or eaten with a spoon. A ripened cheese weighs from 5 to 10 pounds. A cheese of this kind made in the same region is known locally as Tome de Montagne.

The form designated Vacherin Fondu is made in much the same manner as Emmental cheese. The ripened cheese is then melted and spices are added.

VENDÔME.

This is a soft rennet cheese resembling Camembert and Thenay, and is made in the region of Vendôme in the Department of Loir-et-Cher, France.

The warm morning's milk is usually mixed with that of the previous evening, which secures ordinarily a setting temperature of 75° to 85° F., which is desired. The period of setting is four to five hours in summer and five to six hours in winter. The curd is then broken up and put into hoops about 5 inches in diameter and 4 inches in height. After draining for twenty-four hours the cheese is turned and salted, which process is twice repeated at intervals of twelve hours. When sufficiently dried it is placed in the curing cellar where it is often buried in ashes. This cheese is placed by some on a rank with Camembert. The principal market is Paris.

VILLIERS.

This is a soft rennet cheese made in the Department of Haute-Marne, France. It is a square cheese weighing about 1 pound.

VOID.

This is a soft rennet cheese resembling Pont l'Évêque and Limburg. It is made in the Department of Meuse, France. The milk is set with rennet at a high temperature, the whey is removed as rapidly as possible, and the cheeses during ripening are washed frequently with salt water.

VORARLBERG SOUR-MILK.

This, as the name indicates, is made from sour cow's milk. It is semicircular in shape and varies in size. It is essentially a hard cheese.

The sweet milk is put in a kettle and raised to 77° F., and sour thickened milk is added and the mixture stirred and heated to 95°, at which temperature it coagulates. While this is being stirred with a curd scoop the temperature is raised to 105°. The curd is then dipped into forms, where it is turned a few times during twenty-four hours. Salt is rubbed on the surface and the cheese is placed in a room having a temperature of 67°. The cheese is then placed in a cask and held for three days, and salt is sprinkled over the surface daily. The ripening is completed in a cellar. When ripe the cheese is greasy and has a very strong odor and flavor.

WEISSLAK.

This is a soft cured rennet cheese made from cow's milk in the Bavarian Algau, Germany. The cheese weighs about 2½ pounds, and is rectangular in shape, 4½ by 4 by 3½ inches.

WENSLEYDALE.

This cheese derives its name from the valley in Yorkshire, England, in which it is made. It is a rennet cheese made from whole cow's milk. It is cylindrical in shape and weighs from 5 to 15 pounds.

In the old method of manufacture the evening's milk is heated to 100° F., and the fresh morning's milk is added. It is set with sufficient rennet to coagulate it in thirty-five minutes. The breaking or cutting process requires thirty-five minutes, after which the curd is allowed to stand for forty-five minutes at 90°. The whey is then removed, and the curd is put in vats lined with cloth and light pressure is applied for thirty minutes. The curd is broken up and allowed to drain for one hour. It is then milled and is pressed for twenty-four hours, when it is wrapped in cloth, and finally put in brine for three days.

In the new method of manufacture the evening's milk and the morning's milk are mixed in a copper kettle, heated to 95°, and enough rennet is added to coagulate it in forty-five minutes. The curd is then broken up by hand or with a breaker. The whey is removed and the curd dipped into tin hoops where it drains for three hours. It is then turned and drained for another three hours. After pressing for twenty-four hours, the cheese is salted by immersion in brine for three days.

WEST FRIESIAN.

This is a rennet cheese made from skimmed cow's milk. The milk is set in a copper kettle, one hour being allowed for coagulation. The curd is broken up and placed in a wooden tub, where it is kneaded. The curd is allowed to stand for several hours and then salted. It is pressed for three hours, washed in hot water, wrapped in a fine cloth, and again pressed for twelve hours. The cheese is eaten when one week old.

WESTPHALIA SOUR-MILK.

This is a hand cheese made in Westphalia. Sour milk is stirred and heated to 100° F., and placed in a sack and the whey pressed out. The curd is then kneaded by hand and salted, butter and caraway seed or pepper being added. It is then molded by hand, dried for a few hours, and ripened in a cellar.

WHITE.

Fromage Blanc, or White cheese, is a skim-milk cheese made in France during the summer months. The milk is set with rennet at about 75° F. The curd is usually molded into cylindrical forms. The cheese is consumed while fresh and may or may not be salted.

WITHANIA.

This is so called because made with rennet manufactured from withania berries. Cheese made with the rennet of these berries is said to have an agreeable flavor if ripened to the right degree, but it develops an acrid flavor with age. The texture is not so good as with animal rennet. This form of rennet is recommended for use in India, where the religion and prejudice of the people make the use of animal rennet impractical.

ZIEGEL.

This is a cheese made in Austria either from whole cow's milk or from whole milk to which 15 per cent of cream has been added. The cheese measures 3 by 2 by 2½ inches, and weighs about one-half pound.

In making the whole-milk cheese the milk is warmed to 95° F. and sufficient rennet is added to coagulate it in thirty minutes. The curd is broken up with a harp and cut loose from the bottom of the vessel, after which it is allowed to remain undisturbed for thirty minutes. At the end of this time the curd, which is again matted together, is cut into pieces and stirred gently for a considerable time, after which it is allowed to stand again for fifteen minutes. The collected whey is then dipped off and the curd is dipped into forms which are 24 inches long, 5 inches high, and hold the curd of 7½ to 8 gallons of milk. Before the form is filled a cheese cloth is placed in it which helps in turning the curd. The curd remains in the form twenty-four hours to drain and is then cut into measured sizes and placed in another form, where it is allowed to remain for eight days, the curd being turned and the board on which the form rests being changed daily. Salt is then sprinkled on the cheese and for one month it is washed in salt water and rubbed with the hands every day. It is ready for market in eight weeks from the time of making.

ZIGER.

This is a cheese made from the whey obtained in the manufacture of other cheese. It consists principally of albumin, but where no effort is made to separate the fat from the whey the product may contain a relatively high proportion of fat. It is a cheap food product made in all the countries of Central Europe. Among the many names applied to it are Albumin cheese, Recuit, Ricotta, Broccio, Brocotte, Sérac, and Ceracee.

In the manufacture of this product an effort is sometimes made to remove the fat remaining in the whey, but in most cases the fat is allowed to remain. Where it is desired to skim the whey a small portion of very sour whey, previously prepared, is added to the sweet whey and the whole is heated to 160° to 175° F. for a few minutes, when the fat collects on the surface and can be skimmed off. Following this a greater portion of sour whey is added and the whey is then heated nearly to the boiling point, when the albumin is precipitated in a flocculent condition and rises to the surface of the whey. When the whey is not in normal condition the albumin may be precipitated in a powdery mass. This is often prevented by adding 3 to 5 per cent of buttermilk to the whey before the last heating. The casein of the buttermilk is precipitated, the albumin being carried with it. It is considered that this addition of casein injures the product. The albumin when skimmed from the whey is salted and packed in a vessel and may be covered with whey.

A so-called formed Ziger cheese is made by molding the half-dried albumin into squares which may be still further dried. Some of these have local names, such as the Hudelziger made in the Canton of Glarus, Switzerland.

In Vorarlberg the albumin is skimmed from the whey, allowed to cool, placed in cheese cloth, and subjected to increasing pressure in an Emmental cheese press. After twenty-four hours the cheese is put into a salt bath to which sweet cider and vinegar are sometimes added.

A mixture of Ziger and cream prepared in the Savoy is known as Gruau de Montagne. An albumin cheese made from the whey of goat's-milk cheese in the Canton of Graubünden, Switzerland, is known as Mascarponi.

ANALYSES OF CHEESE.

Variety.	Authority.[a]	Number of analyses.	Water.	Fat.	Proteids, amids, etc.	Milk sugar, lactic acid, etc.	Total ash.	Salt in ash.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Alemtejo	Hoffman	1	30.22	38.25	20.87	3.06	7.60	2.90
	Pereira	4 Average	41.11	27.49	21.45	4.66	6.07	2.05
		Maximum	48.39	31.59	24.33	5.24	6.40	3.20
		Minimum	32.97	25.27	17.77	3.82	5.87	1.18
Backstein	Fleischmann	2	73.12	2.76	19.84	2.17	2.11	....
			61.04	6.80	23.85	3.48	4.83	....
	Lindt	2	45.24	28.16	23.14	....	3.46	....
			35.80	37.40	24.44	....	2.36	....
Battelmatt	Eugling	7 Average	47.71	24.08	22.99	2.35	2.87	....
		Maximum	50.53	29.42	24.48	3.35	3.14	....
		Minimum	44.24	20.52	21.22	2.25	2.71	....
Bellelay	Benecke	1	39.62	30.10	25.70	....	4.72	3.35
	Lindt	1	37.59	30.05	28.88	....	3.48	....
Bondon	Chattaway	1	39.50	24.40	9.40	....	.70	....
	Lindet	1	54.30	23.00	16.10	....	5.00	4.30
Brick	Weems	1	38.69	28.86	23.80	....	4.20	....
Brie	Balland	2	48.80	22.45	19.94	4.85	3.96	....
			43.90	28.93	19.04	6.63	1.50	....
	Blyth	1	51.90	24.80	18.10	....	5.00	....
	Duclaux	5 Average	50.04	27.50	18.34	....	4.12	3.22
		Maximum	53.84	29.50	19.94	....	4.37	3.70
		Minimum	46.06	24.60	17.16	....	3.57	2.67
	von Klenze	1	55.69	21.42	17.29	....	5.60	....
	Lindet	1	53.50	22.50	18.00	....	4.00	3.20
	Payen	2	53.99	24.83	14.94	....	5.63	....
			45.25	25.73	18.48	4.93	5.61	....
Brie— American	Arnold	1	41.50	36.15	17.63	....	4.70	....
	Johnson	1	60.20	20.96	15.94	1.37	1.53	.40
Brinsen	Maior	2	49.20	22.30	23.10	1.00	4.40	....
			37.70	32.60	25.20	2.70	5.80	....
	Melikoff	3	43.10	27.70	19.90	1.20	7.30	....
			49.70	27.00	14.30	1.80	6.80	....
			52.20	26.20	14.40	1.30	6.00	....
Burgundy	Balland	1	29.50	38.55	28.84	1.65	1.46	....
Caciocavallo	Sartori	2	19.76	36.71	37.83	....	5.60	3.26
			22.09	35.90	36.06	....	5.80	3.16
	Spica	9 Average	23.68	25.49	29.25	....	7.63	3.39
		Maximum	33.24	30.09	35.09	....	10.50	6.23
		Minimum	15.34	19.00	22.16	....	5.79	2.10
Caerphilly	Chattaway	1	24.80	30.40	37.20	....	3.40	....
Cambridge	Chattaway	1	32.10	47.10	24.60	....	4.40	....
Camembert	Arnold	1	50.41	20.55	25.49	....	3.52	....
	Balland	1	49.00	21.65	18.72	5.95	4.68	....
	Chattaway	2	47.90	21.90	21.80	....	4.70	....
			43.40	22.60	24.40	....	3.80	....
	Duclaux	1	45.24	30.31	19.75	....	4.70	3.69
	Krüger	1	59.42	17.24	17.13	4.70	1.56	....
	Lindet	1	53.80	22.00	17.10	....	4.40	3.20
	Macoir	1	49.87	25.54	18.76	....	5.83	4.01
	Muter	1	48.78	21.35	21.07	....	3.46	....
	Payen	1	51.94	21.05	18.90	4.40	4.71	....
	Rollet	1	52.98	23.71	19.12	....	4.19	3.21
	Stutzer	1	50.90	27.30	18.66	....	3.14	2.21
Cantal	Balland	3	28.50	34.10	28.38	4.46	4.56	....
			35.10	28.30	24.98	7.22	4.40	....
			39.00	26.90	24.22	5.93	3.95	....
	Duclaux	4 Average	43.48	25.70	22.55	6.47	....	2.05
		Maximum	44.80	31.10	24.10	7.50	....	3.10
		Minimum	40.70	22.50	21.50	4.30	....	.80
	Lindet	1	40.90	29.30	20.50	....	4.80	2.60
	Patrick (2)	1	39.92	28.14	28.84	....	4.50	....

[a] See Sources of analytical data for details.

Analyses of cheese—Continued.

Variety.	Authority	Number of analyses.	Water.	Fat.	Proteids, amids, etc.	Milk sugar, lactic acid, etc.	Total ash.	Salt in ash.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Cheddar—American	Caldwell	8 Average	34.04	35.56	26.87	....	3.40	....
		Maximum	38.50	41.03	28.15	....	4.05	....
		Minimum	28.11	31.19	25.57	....	2.71	....
	Clark	79 Average	24.93	32.62	38.01	....	4.42	....
		Maximum	40.04	52.63	55.27	....	8.86	....
		Minimum	3.55	23.20	27.67	....	2.41	....
		89 Average	31.97	27.72	34.62	....	3.54	....
		Maximum	38.16	36.94	41.47	....	4.22	....
		Minimum	26.64	19.58	28.73	....	2.59	....
		13 Average	41.15	15.39	40.10	....	3.33	....
	Cooke	3	35.38	32.50	23.91	....	3.73	....
			37.56	27.70	25.58	....	3.96	....
			34.62	37.52	20.19	....	3.71	....
	Drew	201 Average	31.05	35.54	33.41	....	....	....
	Goessmann	6 Average	40.32	26.05	29.80	....	3.74	....
		Maximum	45.41	37.32	34.94	....	5.14	....
		Minimum	35.83	15.77	22.13	....	2.35	....
	Patrick (1)	15[a] Average	33.09	38.78	21.93	1.99	4.09	....
		Maximum	38.36	49.56	31.76	2.34	4.73	....
		Minimum	26.48	24.77	15.38	1.65	2.43	....
	Snyder	5 Average	32.71	35.25	26.81	....	....	....
	Van Slyke	50[b] Average	37.14	34.05	23.64	....	[c]4.5	....
		156[d] Average	36.84	33.83	23.72	....	[c]5.61	....
		Maximum	43.89	36.79	26.11	....	7.02	....
		Minimum	32.69	30.00	20.80	....	3.12	....
		9[e] Average	36.06	34.43	24.45	.61	3.61	....
		Maximum	41.15	45.36	28.72	.76	5.29	....
		Minimum	32.23	23.27	18.45	.51	1.81	....
		6[f] Average	34.01	36.81	25.69	....	[c]3.50	....
		Maximum	38.10	44.33	30.09	....	4.59	....
		Minimum	29.85	27.22	21.53	....	2.72	....
	Voelcker	4 Average	32.39	31.44	26.57	5.02	4.57	1.49
	Wallace	15[g] Average	36.42	36.95	21.15	1.36	3.81	....
		Maximum	41.65	46.80	32.09	2.68	4.61	....
		Minimum	30.25	21.77	14.11	.41	2.55	....
	Wilson	3	30.53	41.58	23.38	2.45	2.06	....
			31.70	36.18	27.19	1.95	2.98	....
			43.82	5.98	45.04	3.12	2.06	....
Cheddar—Canadian	Chattaway	1	33.30	30.60	27.60	....	3.60	....
	Clark	11 Average	34.07	22.54	40.02	....	3.45	....
		Maximum	36.58	25.67	43.52	....	3.93	....
		Minimum	32.28	20.13	33.82	....	3.14	....
	Shuttelworth	5[g] Average	34.60	35.51	23.18	....	[c]6.70	....
		6 Average[h]	32.53	36.06	23.94	....	[c]7.48	....
		135 Average[g]	36.54	33.81	23.96	....	[c]5.69	....
		135 Average[i]	33.51	32.97	24.94	....	[c]8.58	....
Cheddar—English	Blyth	2 Average	28.10	22.50	45.60	....	4.10	....
	Chattaway	4 Average	35.00	29.02	27.72	....	3.12	....
		Maximum	37.70	30.50	29.00	....	4.30	....
		Minimum	33.00	25.60	26.70	....	3.90	....
	Griffiths	1	36.34	34.36	22.98	2.10	4.22	....
	Hassall	1	30.10	36.54	30.15	....	3.21	....
	Jones	1	36.04	30.40	28.98	....	4.58	....
	Lloyd	31 Average	35.52	30.33	30.04	....	4.05	....
		Maximum	37.73	34.65	35.10	....	4.60	....
		Minimum	32.85	24.00	22.77	....	3.40	....
	Voelcker	13 Average	35.16	30.45	27.80	3.16	3.42	.70
		Maximum	39.43	41.58	32.37	6.80	4.31	1.55
		Minimum	30.32	23.21	23.28	.22	2.06	.09
	Von Klenze	1	35.22	27.91	33.47	....	3.40	....
Cheddar—Queensland	Brünnich	2	31.62	35.17	24.59	....	4.09	1.44
			27.67	37.35	26.24	....	4.04	....

[a] The 15 analyses are each the average of 5 monthly analyses. The green cheese was analyzed by Wallace.

[b] Green cheese made at New York State Agricultural Experiment Station, 1892.

[c] Sugar, ash, etc.

[d] Green cheese made at numerous factories in New York, 1892 and 1893.

[e] Age of cheese, seven weeks.

[f] Age of cheese, five months.

[g] Green cheese

[h] Age of cheese, 1 month.

[i] Cured cheese.

Analyses of cheese—Continued.

Variety.	Authority.	Number of analyses.	Water.	Fat.	Proteids, amids, etc.	Milk sugar, lactic acid, etc.	Total ash.	Salt in ash.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Cheshire	Arnold	1	24.69	37.08	33.36	......	4.85	......
	Balland	1	22.60	39.50	27.16	6.80	3.94	......
	Blades	6 Average	44.59	21.55	29.25	......	4.61	......
		Maximum	52.60	30.67	32.95	......	5.00	......
		Minimum	36.10	9.85	24.44	......	3.90	......
	Chattaway	2	37.80	31.30	25.70	......	4.20	......
			31.60	35.30	26.50	......	4.40	......
	Griffiths	1	27.55	36.00	31.00	2.21	3.24	......
	Lindet	1	31.10	32.30	30.90	......	3.70	1.30
	Payen	2	30.39	25.48	34.75	......	4.78	......
			35.92	26.34	25.99	7.59	4.16	......
	Voelcker	2	36.96	29.34	24.08	5.17	4.45	1.91
			32.50	32.51	26.06	4.53	4.31	1.59
Cotherstone	Griffiths	1	38.20	30.25	23.82	3.81	3.92	......
	Voelcker	2	38.28	30.89	23.93	3.70	3.20	.79
			38.23	29.12	24.38	2.76	5.51	2.55
Coulommiers	Balland	1	50.40	20.45	17.41	4.80	6.94	......
	Lindet	2	53.00	21.50	16.90	......	5.70	4.80
			57.80	25.00	13.00	......	4.10	3.60
Cream—English	Chattaway	2	57.60	39.30	19.00	......	3.40	......
			14.00	68.10	20.10	......	1.20	......
	Hassall	1	30.34	67.32	2.02	......	.32	......
	Payen	1	9.48	59.88	18.40	5.77	6.47	......
	Vieth	8 Average	36.49	56.08	5.28	1.27	.82	......
		Maximum	47.94	66.80	8.77	2.50	1.48	......
		Minimum	27.69	43.76	2.00	.22	.44	......
Cream—French Demi-Sel	Balland	1	52.10	25.20	13.49	8.28	.93	......
	Lindet	1	49.60	34.00	11.80	......	3.00	2.40
Crescenza	Duclaux	1	56.75	21.34	18.91	......	2.90	1.34
Danish Export	Storch	9 Average	45.99	13.41	30.01	5.10	3.63	1.86
		Maximum	49.88	23.70	34.00	5.90	4.17	2.55
		Minimum	38.78	9.34	27.69	2.65	3.33	1.11
Derbyshire	Sheldon	1	31.60	35.20	24.50	4.38	4.24	......
Dorset	Griffiths	1	41.44	27.56	22.25	4.24	4.51	......
	Vieth	1	41.55	8.76	44.09	......	5.60	2.93
Dunlop	Jones	1	38.46	31.86	25.87	......	3.81	......
Edam	Arnold	2	29.23	28.71	33.89	......	8.14	......
			29.56	27.43	32.31	......	8.49	......
	Balland	2	37.90	25.90	27.32	4.08	4.80	......
			38.50	24.29	25.34	9.07	2.80	......
	Cribb	4 Average	51.66	11.85	26.82	......	6.04	......
		Maximum	60.38	24.40	31.92	......	7.33	......
		Minimum	41.70	3.83	24.00	......	5.54	......
	Dahl	3	32.57	32.19	23.98	6.35	4.67	......
			33.62	33.99	23.48	6.34	2.42	......
			42.85	26.73	19.39	5.15	5.62	......
	Hassall	1	30.10	27.57	32.81	......	6.84	......
	von Klenze	1	41.88	24.05	29.47	......	4.60	......
	Lindet	1	42.60	20.00	23.90	......	5.50	3.20
	Mayer	1	33.20	28.00	29.60	2.60	6.60	3.30
	Patrick (2)	1	32.80	29.58	28.41	......	5.55	......
	Payen	2	36.10	27.54	29.43	......	6.93	......
			41.41	25.06	25.63	......	6.21	......
Edam—American	Haecker	3 [a]	48.69	23.21	21.49	3.83	3.02	......
			44.44	25.37	22.69	3.79	2.59	......
			46.80	23.30	24.24	2.92	3.68	......
	Van Slyke	18 [a] Average	47.55	24.42	22.18	......	[b] 5.80	......
		Maximum	55.34	31.75	24.70	......	9.46	......
		Minimum	41.25	19.73	18.95	......	2.51	......
Emmental	Benecke	7 Average	37.77	23.92	30.97	......	6.85	3.80
		Maximum	47.54	34.70	37.65	......	11.09	7.59
		Minimum	30.49	5.75	25.51	......	4.60	1.19
	Hornig	1	33.53	30.29	29.99	.31	5.88	......
	von Klenze	1	35.18	27.99	32.23	......	4.60	......
	Lindt	5 Average	33.00	30.50	30.34	......	4.17	......
		Maximum	37.44	33.37	37.51	......	4.95	......
		Minimum	24.17	28.54	30.44	......	3.38	......
Engandine	do	1	47.30	11.40	36.34	......	4.96	......
Formaggini di Lecco	Cornalba	2	61.00	19.20	16.37	......	3.43	1.90
			16.66	41.50	35.80	......	6.10	3.00
Gammelost	Voelcker	1	42.44	3.36	42.12	9.85	2.22	......
Gervais	Balland	4 Average	51.58	31.98	11.30	4.29	.60	......
		Maximum	58.00	40.47	19.94	7.09	1.42	......
		Minimum	44.70	26.85	7.20	2.13	.25	......
	König	1	52.94	29.75	11.80	2.58	2.93	......
	Richmond	1	33.80	57.79	7.90	......	.50	......
	Stutzer	1	44.84	36.73	15.48	......	2.95	.76

[a] Green cheese.

[b] Sugar, ash, etc.

Analyses of cheese—Continued.

Variety.	Authority.	Number of analyses.	Water.	Fat.	Proteids, amids, etc.	Milk sugar, lactic acid, etc.	Total ash.	Salt in ash.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Gex	Balland	2	31.50	28.85	29.96	5.51	4.18	......
			32.10	32.20	29.86	.34	5.50	......
Gislev	Böggild	1	49.22	2.96	41.53	......	......	......
Gloucester	Bell	1	35.75	28.35	31.10	.31	4.49	......
	Blyth	1	21.40	25.40	48.10	......	4.10	......
	Chattaway	2	33.10	23.50	31.80	......	5.00	......
			37.40	28.10	28.30	......	4.60	......
	Griffiths	1	34.10	37.92	21.68	1.98	4.32	......
	Hassall	1	32.52	29.94	31.70	......	5.84	......
	Jones	1	35.81	21.97	37.96	......	4.25	......
	Voelcker	13 Average	34.80	28.02	27.96	4.37	4.53	1.34
		Maximum	40.88	33.68	31.75	7.44	5.70	2.04
		Minimum	28.10	22.70	24.50	1.22	3.56	.85
Goat-milk—French	Balland	1	20.80	25.90	33.60	15.30	4.40	......
	Lindet	1	64.80	9.20	17.10	......	5.80	4.90
	Patrick (2)	1	17.73	46.64	27.90	......	4.74	......
Goat-milk—Norwegian	Werenskiold	8 Average	20.90	19.86	7.62	46.81	6.06	......
		Maximum	26.53	32.68	10.63	58.07	6.57	......
		Minimum	15.53	10.98	4.43	39.04	5.14	......
Gorgonzola	Bell	1	31.85	27.88	34.34	1.35	4.58	2.11
	Chattaway	2	40.30	26.10	27.70	......	5.30	......
			33.90	26.70	25.80	......	4.60	......
	Duclaux	2	42.80	29.70	23.14	......	4.36	2.21
			38.69	34.07	22.78	......	4.46	2.64
	Hornig	1	36.72	33.69	25.67	.21	3.71	......
	von Klenze	1	26.81	35.29	33.80	......	4.10	......
	Lindet	1	41.50	29.00	19.70	......	4.80	2.60
	Maggiora	3	34.41	37.52	26.75	......	4.08	1.33
			32.43	34.08	25.94	......	[a]6.77	.99
			37.63	36.19	26.94	......	[a]10.46	.92
	Musso	7 Average	37.30	34.67	25.16	1.62	3.82	......
		Maximum	47.10	39.32	28.51	2.00	4.63	......
		Minimum	29.82	29.00	20.33	.91	3.13	......
	Soxhlet	1	43.56	27.95	24.17	......	4.32	......
Gouda	Arnold	1	21.90	24.81	46.95	......	6.32	......
	Cribb	11 Average	54.79	9.02	25.94	......	5.52	......
		Maximum	60.17	18.37	34.22	......	7.30	......
		Minimum	50.46	1.64	22.05	......	4.26	......
	Mayer	1	38.80	31.20	24.40	......	5.60	2.80
	Patrick (2)	1	35.23	29.40	27.01	......	5.41	......
	Vieth	1	42.58	16.18	37.43	......	3.81	3.68
Gouda—American	Haecker	3 [b]	46.03	31.13	18.01	3.04	2.55	......
			46.52	29.04	19.25	3.18	2.88	......
			46.59	28.29	19.64	3.40	3.12	......
Gruyère	Balland	9 Average	29.99	28.19	33.03	4.82	3.96	......
		Maximum	33.10	33.40	37.80	7.40	4.70	......
		Minimum	27.50	23.10	29.54	1.50	3.50	......
	Benecke	1	40.61	26.59	26.18	1.94	4.68	2.10
	Chattaway	2	28.20	28.60	31.30	......	4.70	......
			35.70	31.80	28.70	......	3.70	......
	Duclaux	1	36.00	29.29	30.84	......	3.87	.57
	Lindet	1	35.70	28.00	28.90	......	3.50	.40
	Lindt	2	34.57	29.12	32.51	......	3.80	......
			35.74	30.64	29.95	......	3.67	......
	Payen	2	40.00	24.00	31.50	1.50	3.00	......
			32.05	28.40	33.75	......	4.79	......
Harz Hand	Vieth	1	55.79	1.34	37.01	......	5.86	4.16
	Vieth	3	50.19	1.64	27.72	[c]14.80	5.65	......
			52.49	1.83	22.43	[c]18.00	5.25	4.12
			52.75	1.11	19.38	[c]21.40	5.36	4.08
Hervé	Balland	1	37.50	23.93	20.86	7.71	10.00	......
Ilha	Hoffmann	1	28.39	32.00	30.62	2.85	6.14	1.66
	Pereira	1	36.89	27.15	24.30	7.71	3.95	1.50
Incanestrato	Spica	14 Average	29.07	24.74	30.09	......	9.46	5.04
		Maximum	32.48	37.48	38.66	......	12.70	8.12
		Minimum	26.02	15.88	25.16	......	4.58	.78
Kajmak	Zega	10 Average	31.55	55.79	6.25	2.01	4.50	3.07
		Maximum	36.03	63.82	8.73	3.20	8.38	7.36
		Minimum	23.97	50.16	4.94	.42	2.61	1.10
Kascaval	Maior	2	50.50	14.10	28.10	2.50	4.80	......
			39.10	25.50	28.00	1.40	6.00	......
Katschkawalj	Zega	16 Average	35.25	31.24	24.25	2.84	6.42	3.95
Krutt	Leutner	2	8.59	1.31	78.68	1.93	9.46	8.01
			10.14	1.45	69.74	.81	17.84	13.34

[a] Abnormally high ash content was due to a gypsum preparation with which the cheese was coated.

[b] Green cheese.

[c] Caraway seed.

Analyses of cheese—Continued.

Variety.	Authority.	Number of analyses.	Water.	Fat.	Proteids, amids, etc.	Milk sugar, lactic acid, etc.	Total ash.	Salt in ash.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Laguiole	Balland	1	34.50	25.20	28.70	6.15	5.45	....
Leicestershire	Griffiths	1	34.77	28.00	27.86	5.21	4.16	....
	Voelcker	2	35.21	27.28	27.93	5.54	4.04	1.03
			32.89	29.28	29.06	4.42	4.35	1.21
Leyden	Mayer	1	46.90	11.00	35.90	1.00	5.20	1.40
Limburg—American	Arnold	4 Average	35.64	29.82	28.53	....	5.98	....
		Maximum	48.60	34.98	35.05	....	6.09	....
		Minimum	23.26	21.29	23.58	....	4.82	....
	Johnson	1	42.12	29.40	23.00	.38	5.10	3.51
Livarot	Balland	1	33.80	21.95	31.76	8.05	4.44	....
	Lindet	1	52.20	15.00	25.90	....	4.40	2.90
Mainz Hand	von Klenze	1	53.74	5.65	37.33	....	3.38	....
Maroilles	Lindet	1	40.30	33.50	20.20	....	4.50	3.30
	Payen	1	40.07	28.73	23.31	....	5.93	....
Mascarpone	Fascetti	2	45.88	45.30	8.14	....	.68	....
			43.38	49.50	7.62	....	.50	....
Mont-d'Or	Balland	1	43.20	23.97	20.10	8.84	3.89	....
	Lindet	1	58.70	9.70	25.30	....	4.30	1.90
Münster	Balland	2	45.40	25.90	16.86	6.88	4.96	....
			37.50	29.83	18.17	9.75	4.75	....
	Lindet	1	52.40	24.40	15.50	....	5.00	3.70
Mysost	Dahl	6 Average	23.57	16.26	8.88	44.84	4.76	....
		Maximum	26.49	20.98	10.78	53.03	6.09	....
		Minimum	18.58	9.63	6.79	30.75	3.28	....
	Voelcker	1	24.21	20.80	9.06	41.01	4.92	....
	Werenskiold	22 Average	29.43	4.08	7.66	53.24	5.75	....
		Maximum	38.01	10.54	9.19	61.38	6.38	....
		Minimum	24.37	.07	6.34	46.00	5.06	....
Neufchâtel	Balland	2	50.80	25.15	17.60	5.12	1.33	....
			54.80	20.59	14.43	5.98	4.20	....
	Blyth	1	37.90	41.30	23.10	....	3.40	....
	von Klenze	1	51.72	23.99	20.73	....	3.56	....
	Martin	2	56.08	23.34	16.67	1.42	2.49	1.44
			57.83	21.00	17.00	1.32	2.85	1.90
	Payen	2	34.47	41.91	13.03	6.96	3.63	....
			36.58	40.71	14.18	9.02	.51	....
Neufchâtel—American	Arnold	1	37.45	34.60	24.04	....	3.90	....
	Johnson	1	57.25	22.30	15.03	2.94	2.48	1.42
Nögelost	Dahl	3	48.51	6.13	32.72	8.59	3.79	....
			47.12	7.36	31.63	10.36	3.41	....
			40.54	16.87	31.29	7.90	3.17	....
	Voelcker	3	43.87	15.89	29.93	6.47	4.84	....
			45.39	9.97	33.12	6.39	5.13	....
			42.44	3.36	42.12	9.85	2.22	....
Olivet	Balland	1	28.40	48.16	13.98	5.16	4.30	....
Olmütz	Hornig	1	44.54	3.37	41.04	.16	10.89	....
	Soxhlet	1	52.49	7.70	38.02	....	1.79	....
Parmesan	Arnold	1	23.01	12.49	55.85	....	8.14	....
	Chattaway	1	32.50	17.10	43.60	....	6.20	....
	Duclaux	2	30.09	26.04	38.42	....	5.45	1.76
			32.56	21.75	42.27	....	5.07	1.65
	Lindet	1	34.00	23.00	35.00	....	5.20	1.70
	Manetti	8 Average	32.16	19.13	43.54	....	6.29	....
		Maximum	36.11	23.42	48.93	....	7.18	....
		Minimum	30.20	12.58	38.33	....	5.20	....
	Patrick (2)	1	35.39	19.72	35.55	....	4.82	....
	Payen	2	27.56	15.95	44.08	6.69	5.72	....
			30.31	21.68	34.25	....	7.09	....
	Soxhlet	1	34.57	24.05	35.15	....	6.23	....
Pecorino	Sartori	4 Average	29.80	30.51	33.51	....	6.24	4.95
		Maximum	32.90	31.30	35.59	....	6.84	5.51
		Minimum	27.47	29.96	30.74	....	5.31	4.34
Petit Suisse	Lindet	1	54.60	35.00	7.30	....	.60	.10
Pineapple	Clark	2	3.59	54.56	36.60	....	5.25	....
			5.20	46.46	43.28	....	5.06	....
	Johnson	4 Average	24.07	38.12	29.35	2.49	5.69	2.24
		Maximum	30.95	45.20	34.45	2.75	6.18	2.61
		Minimum	11.62	33.26	27.00	2.16	5.10	1.86
Pont-l'Évêque	Arnold	1	44.57	21.80	30.36	....	3.97	....
	Balland	1	46.40	25.00	20.32	6.68	1.60	....
	Lindet	1	51.00	23.10	17.80	....	4.00	1.90
Pont-l'Évêque—American	Arnold	1	26.02	50.80	20.64	....	2.54	....
Port du Salut	Balland	1	27.70	35.10	31.16	2.04	4.00	....
	Duclaux	2	47.51	25.93	22.56	....	4.00	1.90
			48.02	24.00	24.29	....	3.69	1.56
	Lindet	1	38.10	24.50	24.80	....	5.30	2.20
	Rollet	1	46.46	26.31	23.66	....	3.67	1.31

Analyses of cheese—Continued.

Variety.	Authority.	Number of analyses.	Water.	Fat.	Proteids, amids, etc.	Milk sugar, lactic acid, etc.	Total ash.	Salt in ash.
Potted—								
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
American Club House	Weems	1	38.98	34.01	21.13	......	1.49	......
Imperial	Weems	1	30.63	33.10	26.88	......	4.22	......
Royal Paragon	Weems	1	32.85	31.52	27.74	......	4.13	......
Rabacal	Hoffmann	1	16.45	37.36	35.00	2.93	8.26	2.42
Rebbiola	Cornalba	2	46.56	25.55	19.99	......	7.90	5.80
			45.36	30.56	20.21	......	3.73	1.22
Reblochon	Lindet		53.20	20.50	19.30	......	3.70	1.80
Reindeer milk	Werenskiold	1	27.70	43.11	23.79	2.97	2.43	......
Romadour	Hornig	2	56.60	17.05	18.76	.81	6.78	......
			51.21	9.16	33.60	.02	6.01	......
	von Klenze	1	43.21	10.56	30.18	......	6.10	......
	Lindet	1	60.40	11.90	19.60	......	5.60	3.90
	Patrick (2)	1	55.16	14.76	26.05	......	5.47	......
	Vieth	1	44.55	16.16	32.72	......	6.57	5.80
Roquefort	Arnold	3	28.35	29.98	32.84	......	8.82	......
			28.87	33.70	28.82	......	8.66	......
			22.47	34.02	34.99	......	8.24	......
	Balland	1	28.90	38.30	25.16	3.00	4.64	......
	Bell	1	32.26	34.38	27.16	1.32	4.88	......
	Chattaway	1	29.60	30.30	28.30	......	6.70	......
	Hornig	1	36.93	31.23	25.79	......	4.78	......
	Johnson	1	39.28	29.53	22.62	1.77	6.80	5.27
	von Klenze	1	38.94	34.14	21.92	......	5.00	......
	Lindet	1	36.90	29.50	20.50	......	7.00	5.10
	Muter	1	21.56	35.96	32.24	......	10.24	......
	Patrick (2)	1	34.37	34.54	24.40	......	6.16	......
	Payen	2	26.53	32.31	31.69	......	4.45	......
			34.55	30.14	26.52	3.72	5.07	......
	Sieber	2	23.54	40.13	27.00	......	6.27	......
			36.93	31.23	25.79	......	4.78	......
Ricotta	Sartori	1 [a]	68.47	5.22	18.72	3.97	3.62	......
	Sartori	3 [b]	43.80	36.46	8.66	10.36	.72	......
			42.48	31.64	13.61	11.49	.78	......
			43.29	31.90	12.94	10.75	1.02	......
Saloio	Hoffmann	1	76.25	1.78	11.37	5.28	5.32	2.49
	Pereira	2	54.37	25.84	13.63	2.96	3.20	2.04
			45.81	27.80	15.16	5.97	5.26	3.17
Sap Sago	Arnold	1	13.30	15.52	57.59	......	13.57	......
	Benecke	1	47.02	6.60	37.06	......	10.10	7.53
	von Klenze	1	38.17	12.27	45.73	......	3.83	......
Savoy	Balland	2	52.40	5.90	28.84	9.38	3.48	......
			49.70	6.45	27.32	12.53	4.00	......
Septmoncel	Balland	1	28.20	31.25	32.06	3.99	4.50	......
Serra da Estrella	Büttner	5 Average	43.58	27.69	22.02	2.69	4.00	......
		Maximum	47.98	34.56	24.03	6.13	4.35	......
		Minimum	35.22	19.70	20.40	1.55	3.51	......
	Hoffmann	1	31.87	40.05	22.18	2.24	3.66	.89
	Pereira	12 Average	39.34	27.93	23.48	3.93	5.79	2.57
		Maximum	50.07	37.93	32.10	6.78	8.96	5.26
		Minimum	24.38	19.30	17.83	.78	3.23	.94
Servian	Zega	14 Average	53.99	19.30	21.32	2.63	3.30	1.86
		Maximum	68.84	32.20	32.37	5.12	4.81	3.13
		Minimum	42.10	7.77	14.66	85	2.40	.93
Spalen	Benecke	1	28.14	33.69	30.78	2.55	7.38	4.46
Stilton	Chattaway	3	19.40	42.20	21.10	......	2.60	......
			21.20	45.80	26.30	......	2.90	......
			25.00	34.60	28.40	......	4.10	......
	Griffiths	1	31.22	37.24	24.28	3.40	3.86	......
	Hassall	1	31.37	36.58	27.66	......	4.39	......
	Muter	1	28.60	30.70	35.60	1.08	4.02	.75
	Patrick (2)	1	32.97	39.03	23.19	......	3.24	......
	Voelcker	2	32.18	37.36	24.31	2.22	3.93	.89
			20.27	43.98	33.55	......	2.20	.29
Swiss—American	Arnold	1	38.51	24.84	32.02	......	4.70	......
	Haecker	3 [c]	41.43	29.93	22.13	2.90	3.34	......
			35.91	33.21	24.82	3.32	3.06	......
			38.40	32.40	22.88	3.24	3.48	......
	Johnson	1	33.79	33.25	26.12	1.77	5.07	1.85
Swiss—Russian	Kalantarow	5 Average	32.74	32.26	24.85	4.43	5.78	2.67
		Maximum	35.44	37.20	28.81	6.90	7.44	4.78
		Minimum	29.80	28.97	20.57	.57	4.36	1.45
Swiss—Swedish	Dahl	3	29.34	36.44	23.20	6.11	4.78	......
			38.64	29.13	23.21	4.36	4.39	......
			36.02	32.05	24.76	4.59	2.39	......
Tessel	Mayer	1	54.40	18.30	20.10	1.40	5.80	3.40

[a] From cow's milk. [b] From sheep's milk. [c] Green cheese.

Analyses of cheese—Continued.

Variety.	Authority.	Number of analyses.	Water.	Fat.	Proteids, amids, etc.	Milk sugar, lactic acid, etc.	Total ash.	Salt in ash.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Thenay	Blin	1	30.14	15.00	18.12	......	6.10	4.80
Topfen	König	1	72.44	6.22	16.91	3.07	1.36	......
	Rubner	1	60.27	7.33	24.84	3.54	4.02	......
Trappist	Adametz	1	45.90	26.10	23.30	......	4.00	......
Troyes	Lindet	1	58.70	18.60	14.60	......	4.80	3.70
Vacherin	Benecke	1	54.02	23.74	18.98	2.04	3.08	1.77
	Lindt	1	45.87	27.21	25.29	......	1.63	......
Vendôme	Fallot	6 Average	48.69	20.90	27.97	......	4.43	2.79
		Maximum	56.33	30.61	45.52	......	5.58	3.68
		Minimum	29.63	10.80	17.74	......	3.10	2.08
Viterbo	Sartori	1	28.50	30.93	34.19	......	6.38	5.03
Vorarlberg	Eugling	9 Average	42.99	17.02	31.19	3.79	4.94	......
		Maximum	55.85	31.99	40.11	7.21	6.89	......
		Minimum	32.92	2.82	25.65	1.81	3.79	......
	von Klenze	2	56.61	4.48	36.42	......	2.49	......
			50.58	4.56	42.37	......	2.40	......
Warwickshire	Voelcker	3	31.97	29.08	27.43	7.16	4.36	.72
			33.61	30.04	29.70	1.95	5.60	2.78
			33.53	30.89	28.19	2.84	4.55	1.12
Wensleydale	Chattaway	1	28.30	33.30	27.20	......	3.70	......
Wiltshire	Griffiths	1	37.23	27.82	26.52	3.88	4.55	......
	Jones	1	36.34	28.00	31.12	......	4.41	......
	Voelcker	3	34.44	28.71	29.00	3.60	4.25	1.03
			39.22	19.26	34.22	2.28	5.02	.60
			40.07	25.55	26.81	2.24	5.33	1.41
Ziger	Eugling	3	68.51	3.15	22.13	3.97	2.31	......
			74.74	4.33	14.99	3.93	2.02	......
			68.47	5.22	18.72	3.97	3.62	......
	von Klenze	1	31.00	3.48	64.62	......	.90	......

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Yorkshire-Stilton. *See* Cotherstone.
Young Americas. *See* Cheddar.
Ziegel: Description, 54.
Ziegenkäse. *See* Goat's Milk.
Ziger: Description, 54; analysis, 62.
Zips. *See* Brinsen.

Issued May 28, 1908.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 106.

A. D. MELVIN, CHIEF OF BUREAU.

EXPERIMENTS ON THE DIGESTIBILITY OF PRICKLY PEAR BY CATTLE.

BY

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WASHINGTON:
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1908.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ANIMAL INDUSTRY,
Washington, D. C., March 13, 1908.

SIR: I have the honor to transmit herewith and to recommend for publication as Bulletin 106 of this Bureau a manuscript entitled "Experiments on the Digestibility of Prickly Pear by Cattle," by R. F. Hare, Professor of Chemistry in the College of Agriculture and Mechanic Arts of the Territory of New Mexico.

While the experiments reported in this paper were conducted by Professor Hare in cooperation with the Bureau of Plant Industry, it has been thought advisable to publish the paper as a bulletin of the Bureau of Animal Industry, inasmuch as it deals primarily with the animal side of the subject.

Very respectfully,

A. D. MELVIN,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Washington, D. C., February 10, 1908.

Sir: I have the honor to transmit herewith and to recommend for publication as a bulletin of the Bureau of Animal Industry the accompanying manuscript entitled "Experiments on the Digestibility of Prickly Pear by Cattle."

This paper was prepared by Prof. R. F. Hare, chemist, College of Agriculture and Mechanic Arts of the Territory of New Mexico, under cooperative arrangements with this Bureau, and was submitted for the purpose of publication by Prof. W. J. Spillman, in charge of Farm Management Investigations.

In previous bulletins of the Bureau of Plant Industry and the Agricultural Experiment Station of New Mexico much information has been published upon the practical use and the chemical composition of a large number of prickly pears and other cacti. The value of a feed, however, is not determined by the chemical composition alone; it is also necessary to know the percentage of digestibility of the nutrients found by the chemist. This information is supplied in the accompanying manuscript.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Dr. A. D. Melvin,
Chief, Bureau of Animal Industry.

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EXPERIMENTS ON THE DIGESTIBILITY OF PRICKLY PEAR BY CATTLE.

INTRODUCTION.

Many chemical analyses have been made of a number of different members of the cactus family to determine their value as a feeding stuff for animals.[a] With this data we are enabled to judge with a fair degree of accuracy the amount of the various nutrients contained by many different species of this group of plants, as well as by different parts of the same plant. However, as no record of digestion experiments with any of the cacti has been found, it was impossible to say what proportion of the different nutrients were available to the animals. The increased use of the prickly pear (the flat-jointed members of the genus Opuntia) as a feed for all classes of ruminants, especially for range and dairy cattle, makes it important for the proper preparation of a ration that the feeder know how much digestible nutrients to expect from feeding a given quantity of the plant either alone or mixed with other feeding stuffs. The following experiments have therefore been conducted to determine the digestibility of prickly pear and thus guide the feeder in the preparation of rations from this plant.

The investigations have been conducted in cooperation with the Office of Farm Management Investigations, Bureau of Plant Industry, United States Department of Agriculture. The author acknowledges the assistance of Dr. David Griffiths, of that Office, who has spared neither time nor pains in an effort to make the experiments successful. Acknowledgment is made of the careful and painstaking analytical chemical work of Messrs. S. R. Mitchell and R. B. Deemer.

METHOD OF CONDUCTING DIGESTION EXPERIMENTS.

The principle of conducting a digestion experiment is very simple. First, the animal is fed on the feeding stuff the digestibility of which is to be determined until all other feeds have been removed from the alimentary canal, when the animal is said to be in a condition of equilibrium with this feed. The animal is then placed in a stall specially designed for feeding and for collecting refuse and excreta without waste. It is then fed a weighed amount of the feeding stuff, the composition of which is determined by analysis. All the refuse is collected, weighed, analyzed, and the amount of the several nutrients which it is found to contain is subtracted from the amount of the corresponding nutrients fed. As nearly as possible that portion of the feces which corresponds to the weighed feed eaten is carefully collected, weighed, and analyzed. The amount of the different nutrients found in the feces subtracted from the amount eaten gives the amount of each nutrient digested. This result, multiplied by 100 and divided by the amount eaten, gives the percentage of digestible nutrients, which is called the "coefficient of digestibility."

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[a] See Bulletin 60 of the New Mexico Experiment Station.

DEFINITION OF SOME TECHNICAL TERMS AND DISCUSSION OF THE FUNCTIONS OF FOODS.

Most of the readers of these pages will doubtless be familiar with the technical terms that are used throughout this bulletin and understand how the value of a feeding stuff is determined from its analysis and from the digestion coefficient of the several nutrients, but it may not be amiss briefly to define and discuss them here for the benefit of the few who may not be thoroughly familiar with them. For this reason there are given below definitions of some of the terms used, with the names of the constituents that are usually determined in fixing the value of a feeding stuff, and a brief discussion of the functions of each in the animal body.

It should be remembered that in the feeding of animals the amount of nourishment obtained from any feed by an animal does not altogether depend upon the weight of the feed taken into the body. Green matter, for instance, with 60 to 95 per cent of water will not, of course, furnish as much substance as will cured fodders and grains. The scientific feeder must not only prepare the rations for his animals on the basis of the amount of dry matter present, but it is also necessary that he should know how much nourishment a given amount of this dry matter can furnish them. The dry matter of the different feeds has been found to vary greatly in the amount of nutrients which it contains as well as in its digestibility. A feed which has been adulterated with cotton-seed hulls, chaff, sawdust, or other fibrous and insoluble or difficultly soluble matter would not, for instance, be as digestible, and consequently could not furnish as much nourishment pound for pound, as some feed in which the nutrients were in a form more readily available to the animal. It is, therefore, not only necessary that the amount of dry matter in a feed be known, but it is equally important to know the character and composition of this dry matter.

The animal body is made up of water, mineral matter (or ash), nitrogenous matter (or proteids), and fat. The function of the feed which animals eat is to maintain the supply of this material so that they may grow, perform work, and maintain a healthy condition.

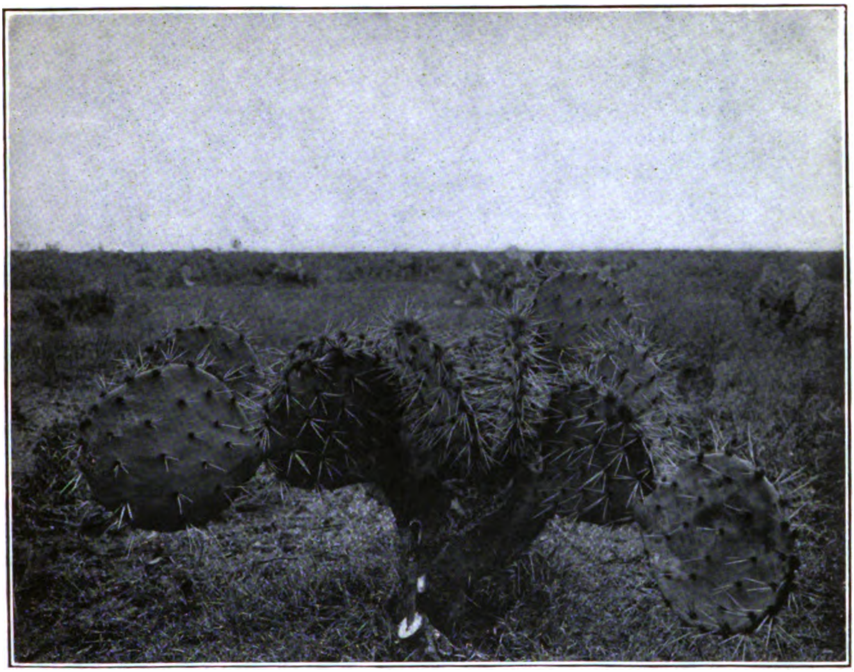

FIG. 1.—OPUNTIA LINDHEIMERI. TWO-YEAR-OLD SECOND GROWTH OF SPECIES FED IN THE FIRST EXPERIMENT.

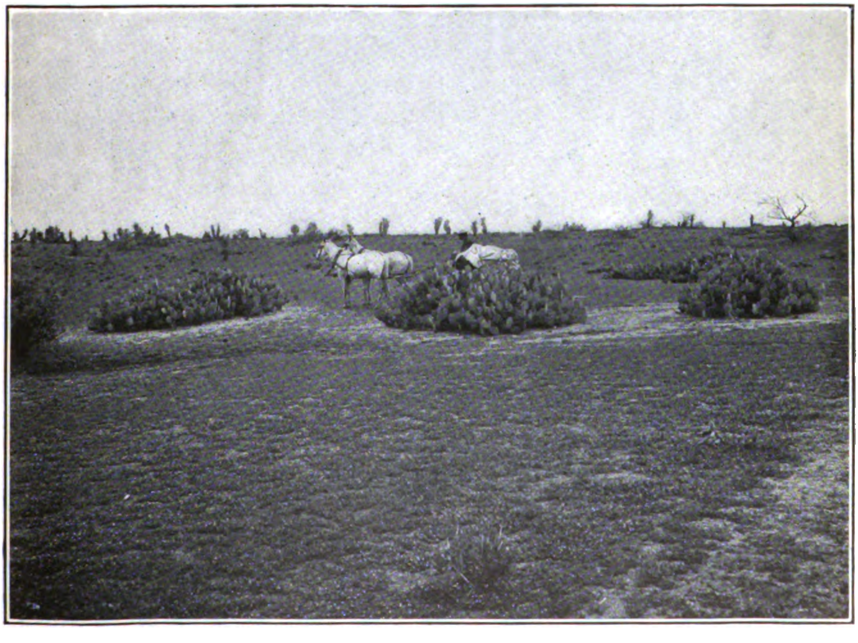

FIG. 2.—OPUNTIA ENGELMANNII CYCLOIDES. OLD PLANTS OF SPECIES FED IN THE THIRD EXPERIMENT.

It is a well-established fact that all feeds have certain groups of substances that perform their peculiar functions in building the different parts of the animal body, and the object of a chemical analysis of any feeding stuff is to separate and determine these groups. They are usually separated into the following: Water, ash, ether extract, crude fiber, protein, nitrogen-free extract, and organic matter. The last named represents a sum of the preceding four, and together with the mineral matter they are all called nutrients. The value and function of each of these classes of nutrients are briefly discussed below.

COMPOSITION OF FEEDING STUFFS.

Water.—All foods, however dry they may appear, contain some moisture. Air-dry corn meal or wheat flour, for example, which may appear perfectly dry will, on the complete removal of their water, be found to have contained from 5 to 15 per cent. Some root crops and vegetables may contain as much as 95 per cent, or even more, of water. The water naturally present in feeding stuffs may cause them to be more succulent and thus doubtless aids their digestion, but an increase in the water means a necessary decrease in the actual amount of food material present, hence its presence instead of adding to merely detracts that much from the value of any feed; especially is this true of the concentrated feeds.

Mineral matter, or *ash*, is that portion which is left after complete combustion of the plant. While a certain amount of ash is necessary for supplying mineral matter to animals and in building bones in the young, there is usually an abundance present in all foods; and for this reason no commercial value is placed on the amount of ash contained in the food, as is the case with proteids, carbohydrates, and fats.

Protein is a name given to a group of very complex compounds which are characterized by the fact that they all contain the element nitrogen combined with carbon, hydrogen, oxygen, and small amounts of sulphur and sometimes phosphorus. Albumen of eggs, casein of milk, and fibrin of blood are examples of protein compounds. Protein is that material in the food which serves as a flesh former, and is the only substance of the food that can be used to build muscular tissue, skin, hair, horns, blood, and connective tissue. It may also, when in abundance, serve the function of the carbohydrates and fats of the food. Alfalfa, cotton-seed meal, all the clovers, and wheat bran are examples of feeds rich in this nutrient; while prickly pear, straw, roots, and tubers contain it in very small amounts. Because of its importance in the dietary, and the fact that it is not present in sufficient amounts in all feeds to supply the needs of animals, it is usually the most expensive of all the nutrients. In one State having a feeding-stuff law a value of 2.3 cents a pound was placed upon the protein which the food contained, while the carbohydrates (nitrogen-free extract and crude fiber) and fats were priced at 0.94 and 1.14 cents, respectively. This is about an average of the prices usually placed on these nutrients.

In the Southwest, where alfalfa, wheat bran, and cotton-seed meal are three of the principal feeds, animals usually get an excess of protein over the amount which they require, and this excess is undoubtedly used to serve the function of the fats and carbohydrates—that is, to furnish heat and other forms of energy and to produce fat. Because of the fact that the feeds mentioned above are the most abundant ones for this section, if a commercial value were placed on their various nutrients the proteids should be cheaper than the carbohydrates and fats, and such is often the case. Wheat bran, cotton-seed meal, and alfalfa are usually found to be cheaper than corn and other starchy grains and hays.

While the various groups of proteid compounds are alike in that the element nitrogen is common to them all, they vary greatly in the proportional amount of nitrogen which they contain as well as in their value for building flesh and muscle. Strange to say, it is not those groups which contain the most nitrogen that are the most valuable for this purpose. Those of most value as flesh formers are the so-called true proteids, or albumin-like substances that contain about 16 per cent of nitrogen. These are most abundant in grains and mature fodders. There are simpler groups of protein compounds which the chemist calls amids and amins, or better, nonproteid nitrogen compounds. They may contain 20 per cent or more of nitrogen. They are the first products formed by the plant in the synthesis of nitrogen compounds from the ammonia of the soil. They may be found in the young and tender parts of the plant or in the fruits, and in roots and tubers. It has been shown that these nonproteids can prevent the waste of tissue when used as a substitute for albumin in food, but they are unable to replace the latter in building flesh.

Fat is the portion that is dissolved when the dried powdered food is treated with ether. This treatment theoretically dissolves fats only, but practically small amounts of gums, resins, chlorophyll, and other substances go into solution with this reagent, and the material thus dissolved is often and perhaps better termed ether extract. The fats, like the carbohydrates, are used as heat and energy producers, and they are about two and one-fourth times as valuable as the latter for that purpose. One pound of fat yields 4,220 calories.[a]

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[a] One calorie is the amount of heat required to raise the temperature of 1 kilogram of water 1 degree Centigrade, or 1 pound of water 4 degrees Fahrenheit.

Crude fiber is the portion of the food that constitutes the framework of the plant. In the analysis it is the part remaining after the finely ground food has been thoroughly treated successively with ether and hot dilute acid and alkali.

Nitrogen-free extract is represented by the sugars and starches, and includes all of those compounds of carbon, hydrogen, and oxygen that are dissolved by boiling the fat-free material consecutively for thirty minutes each in dilute acid and alkali of definite strengths. All of this group of bodies, together with that part of the crude fiber which is digested by the animal, are collectively called carbohydrates. They serve the same function as the fats in the animal system, but are not so concentrated a food. One pound of carbohydrates yields about 1,860 calories, hence we say that fats which yield 4,220 calories per pound have two and one-fourth times the value of carbohydrates as heat producers.

FUNCTION OF THE NUTRIENTS.

The two main functions of food are to produce tissue and to furnish energy. Proteids alone are used for the former purpose, while fats, carbohydrates, and excess of proteids can all be used for the latter. The amount of food used for building tissue is comparatively small, hence the ratio of proteid to nonproteid nutrients may be quite wide, especially for grown animals that are doing hard work.

Since the important functions of any food are performed by the proteids and nitrogen-free nutrients (fats and carbohydrates) they contain, the amount of these present and in a form available to the animal is a measure of the value of that food.

METHOD OF DETERMINING THE DIGESTIBLE NUTRIENTS OF PRICKLY PEAR FROM THE COMPOSITION AND DIGESTION COEFFICIENT.

An average of several analyses of a certain variety of prickly pear (*Opuntia lindheimeri*) shows it to have the following composition: Water, 83.41 per cent; ash, 3.48 per cent; protein, 0.75 per cent; ether extract, 0.31 per cent; crude fiber, 2.64 per cent; nitrogen-free extract, 9.41 per cent; total organic matter, 13.11 per cent.

By feeding this plant to steers we find the following coefficient of digestion of the nutrients present for this class of animals: Protein, 58.25 per cent; fat (ether extract), 67.90 per cent; crude fiber, 41.32 per cent; nitrogen-free extract, 82.59 per cent. With these figures we calculate the following digestible nutrients from the above analyses by multiplying each nutrient by its coefficient: Proteids, 0.45; fat, 0.21; carbohydrates, 7.77. The nutritive ratio, or the ratio between digestible proteids and nitrogen-free material, i. e., fat × 2.25 + total carbohydrates, in this sample of the plant, is 1 to 18.3.

PREPARATION OF STANDARD RATIONS.

As before stated, the value of a feed does not necessarily depend upon the amount of proteids, carbohydrates, and fats which it contains, but rather upon the amount of these contained in the feed that is available to animals. If digestion experiments show that a comparatively large amount of the nutrients pass into the feces, then in order that the animal may secure sufficient nutrients to supply the purpose sought there must be a corresponding increase of the ration. For the guidance of the feeder in the proper preparation of his ration, the digestion coefficient has been determined for practically all ordinary feeds and for the several kinds of farm animals. Experience has proven that the best results are obtained in feeding when the digestible nutrients are fed to the animal in certain definite amounts. Tables of feeding standards have been compiled by German and American scientists in which are given the daily amounts of each nutrient required by our common farm animals of a given weight and for a specific purpose. In the feeding of milch cows, for example, the standard fixed by the German scientist Wolff is the one probably most used in this country at present. It is based on observation of the feeding practices of the best German feeders, together with feeding experiments by trained specialists. There is a prevalent opinion in the United States that the Wolff standard for milch cows is somewhat higher in proteids than is necessary for the best American ration. Several attempts have been made by scientists in the United States to determine what the proper standard is for this country. Below is given a table taken from the Connecticut (Storrs) Experiment Station report for 1894, in which is given the German standard, together with four rations which have been proposed by different authorities for the United States.

TABLE 1.—*German (Wolff's) standard ration, together with averages of some American rations and a tentatively suggested ration per 1,000 pounds live weight.*

Rations.	Organic matter.	Digestible nutrients.				Nutritive ratio.
		Protein.	Fat.	Carbohydrates.	Fuel value.	
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Calories.*	
Wolff's (German) standard	24.0	2.50	0.40	12.50	29,600	1:5.4
Average of 128 American rations, compiled by the Wisconsin Experiment Station	24.5	2.15	.74	13.27	31,250	1:6.9
Average of 16 rations as fed in Connecticut in 1892–93	26.4	2.48	.94	14.09	34,800	1:6.5
Average of 25 rations as fed in Connecticut in 1892–94	26.8	2.51	.90	13.92	34,350	1:6.3
Tentatively suggested ration [a]	25.0	2.50	.5 to .8	13 to 12	31,000	1:5.6

[a] In this suggested ration the fuel value could be supplied by about 0.5 pound of digestible fat and 13 pounds of digestible carbohydrates; by 0.6 pound of digestible fat and 12.5 pounds of digestible carbohydrates; or by 0.8 pound of digestible fat and 12 pounds of digestible carbohydrates.

It will be seen from the table that about the only material change recommended by American scientists consists in an increase of the fats and carbohydrates. It would appear that this much difference might almost result from individuality, and the feeder would be safe in using any of these rations that common sense, good judgment, and his experience with the individual animals would indicate to him to be best. In New Mexico, where proteid feeds are cheap, the nutritive ratio of the Wolff standard would probably not be too narrow. In fact, narrower rations than those proposed by him are used here constantly with splendid results.

By the use of the above table a balanced ration can be prepared from prickly pear when its digestible nutrients are known, by so mixing it with other feeds as to obtain the nutrients in the right proportion. Suppose, for example, we desire to prepare a ration composed in part of prickly pear for a 1,000-pound milch cow yielding 22 pounds of milk per day. Using the Wolff standard of 2.5 pounds protein, 0.5 pound fats, and 13 pounds carbohydrates as our basis, and feeding 100 pounds of prickly pear per day, the cow would get the following nutrients, as calculated above from the species *Opuntia lindheimeri:* Proteids, 0.45 pound; fats, 0.21 pound; carbohydrates, 7.77 pounds. This leaves a balance of 2.05 pounds protein, 0.29 pound fat, and 5.23 pounds carbohydrates to be supplied by some other feed. Since the ratio of proteids to nonproteids (nutritive ratio) in this variety of pear is 1 to 21.7, and a ratio of 1 to 5.7 is the Wolff standard for such a cow, it is evident that some feed rich in protein should be mixed with the prickly pear to narrow it down to this ratio. Cotton-seed meal, wheat bran, or alfalfa could be used for this purpose, but cotton-seed meal, if fed in quantity, contains so much protein that it makes, perhaps, too narrow a ration for the best results; besides, animals scour when fed cotton-seed meal and prickly pear alone, and if possible these should be fed in connection with some cured fodder.

In Bulletin 60 of the New Mexico Experiment Station a balanced ration of prickly pear is discussed and rations containing this feed are suggested. At the time the bulletin was written the coefficient of digestion for prickly pear had not been determined, and in calculating the rations its digestibility was assumed to be the same as that of green corn fodder.[a] That the digestion coefficient of prickly pear, calculated from the coefficient of green corn fodder, is very similar to that obtained from actual digestion experiments may be seen from the table following.

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[a] See Bulletin 77, Office of Experiment Stations, United States Department of Agriculture, p. 82.

TABLE. 2.—*Total nutrients of prickly pear (Opuntia lindheimeri), the digestible nutrients as obtained by experiment, and the calculated digestible nutrients obtained by using the digestion coefficient of green corn fodder.*

Name of nutrient.	Protein.	Fat.	Nitrogen-free extract.	Fiber.	Carbohydrates.
Prickly pear:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Composition	0.75	0.31	9.41	2.61	2.01
Digestible nutrients as determined	.44	.21	7.77	1.09	8.86
Digestible nutrients as calculated from data obtained with green corn fodder	.49	.22	6.87	1.76	8.63

From the foregoing table it may be seen that the coefficients of digestion of green corn fodder that were used for calculating the digestibility of prickly pear in the preparation of a balanced ration in Bulletin 60 are sufficiently close to allow the ration there given to remain unchanged.

The proteids of the prickly pear do not appear to be quite as digestible as those of green corn fodder, the fats are about the same in both, while the nitrogen-free extract is more for the prickly pear, the crude fiber is less, but the total digestible nutrients are about the same, being slightly in favor of prickly pear.

PLAN OF THE EXPERIMENTS.

THE ANIMALS USED.

Five different digestion experiments are included in this study. In all cases wild range steers from 2 to 3 years old were the animals selected. The steers being very wild were quite difficult to handle properly, but it seemed impossible to get tame steers and at the same time those accustomed to eating prickly pear. In fact, a gentle steer is practically unknown on the ranges. Plenty of milch cows were available, but were not used because of the difficulty of keeping separate the liquid and solid excreta. Both sheep and goats eat prickly pear, but none that could be used in this work were found convenient; besides, steers were preferred, it being deemed more desirable to get the data for cattle, since they are fed this plant more extensively than are any other animals. Experience has shown that there may be a slight difference between the digestion coefficient obtained from sheep, goats, and cattle, yet for all practical purposes this factor may be assumed to be the same for all ruminants. Two steers were used in each of the experiments so as to minimize any difference due to individual animals or slight errors due to manipulation. It is usually customary to use two animals in this work; sometimes more are used, and of course the larger the number the more trustworthy should be the result.

THE DIFFERENT RATIONS USED.

The first experiment was conducted at San Antonio, Tex., in January, 1906. In this experiment the steers were fed prickly pear alone for about three weeks. During the last four days they were confined in stalls and all their feed and refuse were carefully weighed, the feces and urine being collected in a manner described later.

Experiments Nos. 2, 3, 4, and 5 were all conducted in the spring of 1907 at the Agricultural College of New Mexico. Grade Hereford steers were used in each experiment.

In experiment No. 2 prickly pear was fed alone, as in experiment No. 1 conducted at San Antonio the previous year.

In experiments Nos. 3 and 4 prickly pear was mixed with other feeding stuffs (alfalfa in experiment No. 3, cotton-seed meal in No. 4), to determine what effect, if any, these feeds might have on the digestibility of the prickly pear, or vice versa.

In experiment No. 5 the digestibility of the alfalfa, which was fed with prickly pear in experiment No. 3, was determined.

The digestibility of the cotton-seed meal when fed alone was not determined as was done with alfalfa, it being decided to accept the digestion coefficients secured by other experiments for this feed.

Summarized, the experiments were made to determine—

(1) Digestibility of prickly pear (*Opuntia lindheimeri*).
(2) Digestibility of prickly pear (*O. lævis?*).
(3) Digestibility of prickly pear (*O. engelmannii cycloides*) and alfalfa.
(4) Digestibility of prickly pear (*O. engelmannii cycloides*) and cotton-seed meal.
(5) Digestibility of a fair quality of second-cut alfalfa.

DESCRIPTION OF THE STALLS.

A good idea of the stalls used in these experiments may be obtained from figure 1. They were made of proper length and breadth so that the steers could lie down comfortably, but not wide enough to permit them to turn around. The stalls used at the college were about 8½ feet long and 4 feet wide. Most of the floor, which had a slight inclination from both front and rear toward the center and to one side of the stall, was covered with thick rubber cloth. The inclination of the floor allowed all the urine to run to the middle of the stall, where it was caught in a galvanized iron trough and conducted to vessels outside the stall, as shown in the illustration. The urine trough ran the entire width of the stall near the center and just beneath the floor. A narrow 1-inch strip was nailed across the floor of the stall in such a manner as to prevent any liquid feces from running into the urine trough. The side and back walls of the stalls were lined with galvanized iron wherever there was any danger from spattering of feces. The feed trough was made perfectly tight, and so placed that the animals could eat with comfort and not waste their feed. The stalls were covered and placed in a position to make the animals as comfortable as possible.

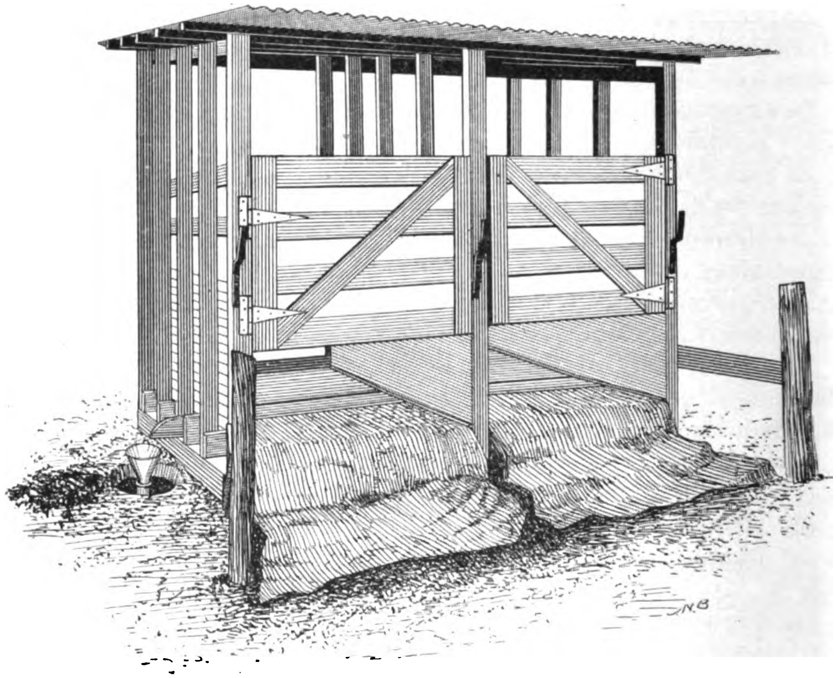

FIG. 1.—The stalls used in experiments Nos. 2 to 5.

THE FEEDING.

The preliminary feeding period which preceded the experiment proper was never less than seven days, usually more. In this time there was little possibility of any other food being left undigested in the animals' systems. The steers were then placed in the stalls and a weighed amount of the feed was given them twice each day, a sample being reserved for analysis each time before weighing. The prickly pear was first prepared by singeing the spines by means of a brush fire and chopping the singed stems into small pieces with a large knife or root chopper. A quantity of this feed was kept before the animals most of the time for a period of five days, the refuse being removed and weighed twice each day.

COLLECTING THE FECES.

After the preliminary period of a week or more the steers, which during this time had the run of a small inclosure, were placed in their stalls, but the feces were not collected for twenty-four hours afterwards. This was assumed to be the feces from the first feed that was weighed to them the day before. While this is an unsatisfactory method of determining the first weighed feed, it seemed the best that could be done, and it is believed that the error resulting, if any, was not large when the sum of the feces for the five days was taken. It is a difficult matter to mark the beginning of a digestion experiment with steers. In experiments of this kind with man or animals other than ruminants it is customary to use charcoal or some indigestible material of a different color from the feces, which will give a distinct line of separation between feces from weighed and unweighed food, but with the steers the marking of the weighed feed was not so simple. The experiment was tried of giving a small handful of weighed uncrushed corn as recommended in Minnesota Experiment Station Bulletin 99, but the method was found unsatisfactory in this instance because at times the corn did not appear for three or four days, and then it did not all come together.

Usually in digestion experiments with animals it is customary to fasten rubber bags to them by means of a harness to catch the excreta, but this was wholly impracticable with any range steers that could be obtained. Hence it was necessary to arrange the stalls as well as we could for the separation of feces and urine, and to keep an attendant constantly with the steers during the entire experiment. The work was made unusually difficult because the steers were wild and somewhat nervous all the time. Then, too, as the prickly pear caused diarrhea or "scouring" in the animals, extra care had to be exercised to prevent loss of feces from spattering and otherwise; but it is believed that with the precautions taken the method used was quite as satisfactory as the method of collecting in bags.

COLLECTING THE URINE.

Since the digestibility of a food is shown by the difference between the amount eaten and the amount undigested, all of which is found in the feces, there can be no object in collecting the urine when the digestibility of the food is all that is sought. This is therefore collected only when it is desired to know something of the metabolism of the nitrogen of the food. The solid matter of urine other than the inorganic salts is principally urea and other highly nitrogenous compounds resulting from a waste of muscular and other nitrogenous tissue, the kidneys being the principal organs through which this waste is excreted from the body. The excess of nitrogenous matter from the digested proteids of the food may also be found in the urine.

In the experiments the urine was collected, weighed, and analyzed for the purpose of studying the income and outgo of nitrogen with the different feeds, in some of which the proteids were present in very small amounts, while in others the nutritive ratio was much narrower than that given by Wolff for oxen at rest in stalls. The results of this study of nitrogen metabolism are given in Table 17, and are discussed under "Income and outgo of nitrogen" in another part of this bulletin.

PREPARATION OF THE SAMPLES.

Samples of the feed and refuse were collected twice daily, and of feces and urine once each day. After a moisture determination had been made on the samples of feed and refuse for each day the dry matter from them all was mixed for one composite sample.

The daily samples of feces and urine were analyzed separately in all experiments except for the urine in experiment No. 1. In this instance one composite sample was made of all daily samples.

In collecting the samples of feed, refuse, and feces about 200 grams of the fresh material were taken in a large porcelain dish and placed in the hot New Mexico sun where it soon reached an air-dry condition. The dry material was then pulverized and was ready for the analyses, which were made according to the methods of the Association of Official Agricultural Chemists.

REPORT OF THE EXPERIMENTS.

EXPERIMENT NO. 1.—DIGESTIBILITY OF PRICKLY PEAR (*Opuntia lindheimeri*).

This experiment was conducted at the ranch of Mr. Alexander Sinclair, near San Antonio, Tex. This locality was selected because in that section the prickly pear grows much more luxuriantly than it does in the vicinity of the New Mexico Agricultural College, and cattle there are more accustomed to eating the plant than are the cattle of New Mexico; in fact, the steers that were fed at the college had to be trained to eat prickly pear, and in consequence ate not more than half the amount eaten by the Texas steers. Moreover, during part of the time, at least, what they did eat was little relished, except when fed in connection with some other feed.

In this experiment two 3-year-old range steers, weighing about 800 pounds each, were used. They were fed for a preliminary period of ten days before being placed in the stalls. The experiment began at noon January 2, 1906, and continued until noon of January 6. The steers were placed in a barn with plenty of light and air, and were well protected from the cold. They remained in good condition during the entire experiment, except that they scoured quite badly, as animals always do on an exclusive prickly pear diet. The fact that these animals scoured is not surprising when one considers that in eating 100 pounds of prickly pear, the average daily ration during the five days, they consumed 2.95 pounds of inorganic matter or ash, which doubtless means more than twice this amount of salts more or less purgative in their character. The steers also obtained 86.4 pounds (or over 10 gallons) of water from 100 pounds of prickly pear, and this would doubtless aid the salts in their purgative action. The water obtained from the feed was more than was drunk by the steers in experiment No. 5 where alfalfa alone was fed and in which an average of only 48 pounds a day was drunk. The steers in experiment No. 1 took no water during the experiment except that obtained from the feed.

In Table 3 is given the composition of the composite sample made up of daily samples of the pear fed and refused during the four days the animals were in the stalls. There are also given analyses of daily samples of the feces from both steers. From these figures with the weights of the dry matter in feed and feces have been calculated the data given in Table 4.

Table 3.—*Experiment No. 1—Composition of the prickly pear fed, of the refuse, and of the feces.*

[Nutrients reported water free.]

	Water.	Ash.	Protein.[a]	Fat.[a]	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Prickly pear, as fed	86.38	2.95	0.72	0.19	1.77	8.02	10.70
Prickly pear, water free		21.69	5.27	1.42	13.00	58.62	78.31
Refuse water free—							
Steer No. 1		21.69	5.27	1.42	13.00	58.62	78.31
Steer No. 2		21.69	5.27	1.42	13.00	58.62	78.31
Feces steer No. 1—							
First day	85.76	36.91	6.28	1.51	22.94	32.36	63.09
Second day	85.59	42.64	6.28	1.30	21.73	28.05	57.36
Third day	88.63	42.79	7.79	1.57	19.38	28.47	57.21
Fourth day	86.65	42.34	5.97	1.27	21.06	29.36	57.66
Feces steer No. 2—							
First day	82.83	45.93	5.85	1.24	21.46	25.52	54.07
Second day	81.39	45.33	6.40	1.31	20.91	26.05	54.67
Third day	88.89	36.74	7.79	1.36	19.82	34.29	63.26
Fourth day	87.62	35.32	5.58	1.18	23.47	34.45	64.68

[a] The words "protein" and "fat" are used here and elsewhere in this bulletin to denote, respectively, crude protein and ether extract.

TABLE 4.—*Weight of the feed, refuse, and feces in experiment No. 1, with the calculated digestion coefficients.*

STEER NO. 1.

	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Total prickly pear fed	25,542.7	5,540.0	1,346.1	362.7	3,320.6	14,973.3	20,002.7
Total prickly pear refused	441.3	95.7	23.3	6.3	57.4	258.6	345.6
Total prickly pear eaten	25,101.4	5,444.3	1,322.8	356.4	3,263.2	14,714.7	19,657.1
Feces:							
First day	1,913.3	706.2	120.2	28.9	438.9	619.1	1,207.1
Second day	1,546.2	659.3	97.1	20.1	336.0	433.7	886.9
Third day	2,063.7	883.1	160.8	32.4	399.9	587.5	1,180.6
Fourth day	2,730.1	1,155.9	163.0	34.7	575.0	801.5	1,574.2
Total feces dropped	8,253.3	3,404.5	541.1	116.1	1,749.8	2,441.8	4,848.8
Digested	16,848.1	2,039.8	781.7	240.3	1,513.4	12,272.9	14,808.3
Coefficient of digestion (per cent)	67.12	37.46	59.03	67.42	41.31	83.40	71.21

STEER No. 2.

	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
Total prickly pear fed	24,422.6	5,297.3	1,287.1	346.8	3,174.9	14,316.5	19,125.3
Total prickly pear refused	889.4	192.9	46.9	12.6	115.6	521.6	696.7
Total prickly pear eaten	23,533.2	5,104.4	1,240.2	334.2	3,059.3	13,794.9	18,428.6
Feces:							
First day	1,697.6	779.7	99.3	21.1	364.3	433.2	917.9
Second day	2,390.5	1,083.6	153.0	31.3	499.9	622.7	1,306.9
Third day	1,749.8	642.9	136.3	23.8	346.8	600.0	1,106.9
Fourth day	2,489.5	879.3	138.9	29.4	584.3	857.6	1,610.2
Total feces dropped	8,327.4	3,385.5	527.5	105.6	1,795.3	2,513.5	4,191.9
Digested	15,205.8	1,718.9	712.7	228.6	1,264.0	11,281.4	14,236.7
Coefficient of digestion (per cent)	64.61	33.67	57.47	68.38	41.32	81.78	77.03
Average per cent digested by two steers	65.86	35.57	58.25	67.90	41.32	82.59	74.12

NOTE.—453.4 grams equal 1 pound.

The figures given above speak fairly well for the digestibility of the prickly pear. The coefficient for dry matter is equal to an average of that obtained from our best feeds.

This experiment shows that the digestion coefficient for the ash of prickly pear is low, but this was to be expected because of the large amount of ash always present in these plants. Animals assimilate more ash from prickly pear with the low digestion coefficient of this nutrient than they obtain from other feeds. For example, the ash assimilated from 100 pounds of prickly pear by steer No. 1 of this experiment amounts to 1.11 pounds; while steer No. 1 in experiment No. 5, where alfalfa alone was fed, assimilated only 0.63 pound from 15 pounds of alfalfa.

The digestibility of the other nutrients is found to compare very favorably with other standard feeds, the coefficient for nitrogen-free extract being unusually high.

EXPERIMENT NO. 2.—DIGESTIBILITY OF PRICKLY PEAR (*Opuntia lævis?*).

This experiment and the three following were all conducted with the same two steers. They were grade Herefords that had been grain fed and were ready for the market at the time the experiment was begun. This fact rendered them less satisfactory for feeding on prickly pear alone; and to make the matter worse the feeding was done in the spring, when many of the joints were young and least palatable to animals. In view of this fact the daily ration, amounting to only 53.52 pounds for steer No. 1, and 72.18 pounds for steer No. 2, was considerably short of enough for maintenance. The animals lost flesh rapidly on this ration, but unfortunately we can not say just how much, since they were not weighed after the experiment. However, by reference to Table 17, it may be seen that the excreted nitrogen during the five days was in excess of the nitrogen of the feed by 46.9 grams for steer No. 1 and 63.2 grams for steer No. 2, making a daily loss of 58.6 grams of proteids for steer No. 1 and of 79 grams for steer No. 2.

By referring to Table 5 it will be seen that both steers received much less than a maintenance ration. Steer No. 1 ate only 6.64 pounds of dry matter, when for maintenance he should have had 15.1 pounds. Steer No. 2 ate 9.36 pounds out of 16.7 pounds required, and the nutritive ratio of the dry matter was 1 to 33 for both steers.

The results of this experiment agree fairly well with those obtained at San Antonio in experiment No. 1, the greatest difference being in the amount of protein and fiber digested. The increased amount of fiber digested in this experiment might be explained by the fact that the plants were mostly young and succulent joints in which the fiber had not developed to such an extent from the more digestible hydrated cellulose. Steer No. 1 obtained 46.3 pounds of water from the prickly pear eaten. He drank in addition an average of 7.6 pounds daily. Steer No. 2 obtained 62.4 pounds of water from his feed and drank in addition 5.4 pounds.

TABLE 5.—*Experiment No. 2—Composition of the prickly pear fed, of the refuse, and of the feces.*

[Nutrients reported water free.]

	Water.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Prickly pear fed	86.45	2.85	0.57	0.23	2.25	7.65	10.70
Prickly pear, water free		21.05	4.22	1.71	16.61	56.41	78.95
Refuse, water free—Steer No. 1. Steer No. 2.		21.82	4.64	1.46	17.14	54.94	78.18

TABLE 5.—*Experiment No. 2—Composition of the prickly pear fed, of the refuse, and of the feces*—Continued.

	Water.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
Feces of steer No. 1:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
First day	76.72	38.85	6.98	1.33	18.94	33.90	61.15
Second day	75.40	44.49	6.87	1.28	19.22	28.14	55.51
Third day	73.36	38.62	7.42	1.51	21.64	30.81	61.38
Fourth day	74.55	31.74	8.49	1.77	20.07	37.93	68.26
Fifth day	72.04	31.42	6.81	1.95	24.52	35.30	68.58
Feces of steer No. 2:							
First day	82.50	37.07	7.28	1.49	21.38	32.78	62.93
Second day	81.04	41.75	5.78	1.16	21.07	30.24	58.25
Third day	80.01	40.01	5.91	1.40	19.82	32.86	59.99
Fourth day	84.46	31.32	5.91	1.54	19.56	41.67	68.68
Fifth day	76.69	36.86	6.91	1.98	24.57	29.68	63.14

TABLE 6.—*Weight of the feed, refuse, and feces in experiment No. 2, with the calculated digestion coefficient.*

STEER NO. 1.

	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Total prickly pear fed	18,749.3	3,946.7	791.2	320.6	3,114.3	10,576.5	14,802.6
Total prickly pear refused	3,694.5	806.1	171.4	53.9	633.2	2,029.9	2,888.4
Total prickly pear eaten.	15,054.8	3,140.6	619.8	266.7	2,481.1	8,546.6	11,914.2
Feces:							
First day	912.6	354.5	63.7	12.0	172.8	309.5	558.1
Second day	1,287.8	572.9	88.5	16.5	247.5	362.4	714.9
Third day	690.0	266.5	51.2	10.4	149.3	212.6	423.5
Fourth day	917.5	291.2	77.9	16.2	184.1	348.1	626.3
Fifth day	1,382.1	434.3	94.1	27.0	339.0	487.7	947.8
Total feces dropped	5,190.0	1,919.4	375.4	82.2	1,092.7	1,720.3	3,270.6
Total digested	9,684.8	1,221.2	244.4	184.5	1,388.4	6,826.3	8,643.6
Coefficient of digestion (per cent)	65.52	38.88	39.43	69.18	55.96	79.87	72.55
STEER NO. 2.							
Total prickly pear fed	23,753.8	5,000.2	1,002.4	406.2	3,945.5	13,399.5	18,753.6
Total prickly pear refused	2,530.0	552.0	117.4	36.9	433.6	1,390.0	1,978.0
Total prickly pear eaten.	21,223.8	4,448.2	885.0	369.3	3,511.9	12,009.5	16,675.6
Feces:							
First day	1,554.5	576.3	113.2	23.2	332.3	509.5	978.2
Second day	1,784.1	744.9	103.1	20.7	375.9	539.5	1,039.2
Third day	1,228.0	491.3	72.6	17.2	243.4	403.5	736.7
Fourth day	1,434.3	449.2	84.8	22.1	280.5	597.7	985.1
Fifth day	1,981.4	730.3	136.9	39.2	486.8	588.2	1,251.1
Total feces dropped	7,982.3	2,992.0	510.6	122.4	1,718.9	2,638.4	4,990.3
Total prickly pear digested	13,241.5	1,456.2	374.4	246.9	1,792.0	9,371.1	11,785.3
Coefficient of digestion (per cent)	62.40	32.74	42.31	68.86	51.02	78.03	70.12
Average coefficient of digestion.	63.96	35.81	40.87	69.02	53.99	78.95	71.39

EXPERIMENT NO. 3.—DIGESTIBILITY OF PRICKLY PEAR (*Opuntia engelmannii cycloides*) AND ALFALFA.

Since prickly pear will not furnish a balanced ration when fed alone, but requires some feed of a relatively high protein content as a supplement, the effect of alfalfa on the digestibility of the prickly pear has here been tried. Steer No. 1 was given an average of 4.5 pounds of alfalfa daily, while 4.72 pounds was given to steer No. 2. In addition they were given all the prickly pear they would eat, which was 42.16 pounds for steer No. 1, and 57.18 pounds for steer No. 2. The prickly pear used was *Opuntia engelmannii cycloides*, which is a larger stemmed plant than most of the native prickly pears, and the animals seemed to relish it better than they did *O. lævis?*, the variety used in the preceding experiment.

The results obtained in feeding this ration to steer No. 1 were for some unaccountable reason very unsatisfactory. The dry matter digested amounted to only 56.81 per cent and the ash to 16.87 per cent, while the protein coefficient was minus 16.54 per cent. This negative value for protein means that the protein of the feces amounted to more than that of the feed, which, of course, is an error. Whether this was due to blood or cleavage products in the feces, we can not say. The percentage of nitrogen in the feces was unusually high, but duplicate analyses of these were made that checked within reasonable limits of working error. Only 29.92 per cent of the fiber was digested by this animal, but the amounts of fat, nitrogen-free extract, and organic matter seemed to compare favorably with the coefficients of these nutrients from the feed of steer No. 2. Assuming the digestibility of prickly pear fed in this experiment to be an average of the coefficients for the two varieties determined in experiments Nos. 1 and 2, we have by the use of this factor calculated the digestion coefficient of the alfalfa that constituted the other portion of the ration. The coefficients obtained for alfalfa with steer No. 1 are quite as unsatisfactory as were those obtained from this steer for prickly pear. They were all far below the normal digestion coefficients for this feeding stuff, the results for ash being minus 38.9 per cent. While the results obtained from steer No. 1 with this ration are all recorded in the following tables, it is very evident that the coefficients found can not be used in the calculation of rations of either prickly pear or alfalfa. We have therefore omitted them from all averages.

With steer No. 2 the results show an increase in the digestibility of the nutrients of both feeds, and this is just what might be expected with this ration.

For a comparison of the digestion coefficients of prickly pear and alfalfa obtained in the following table with those of prickly pear obtained in the other experiments and of alfalfa obtained both here and at the other experiment stations, see Table 14.

TABLE 7.—*Experiment No. 3—Composition of the prickly pear and alfalfa fed, of the refuse, and of the feces.*

[Nutrients reported water free.]

	Water.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Prickly pear water free	None.	18.75	2.98	1.48	12.22	64.57	81.25
Alfalfa water free	None.	10.09	14.09	2.07	32.28	41.47	89.91
Refuse of prickly pear, steers Nos. 1 and 2		18.75	2.98	1.48	12.22	64.57	81.25
Refuse of alfalfa, steers Nos. 1 and 2	None.	None.	None.	None.	None.	None.	None.
Feces of steer No. 1:							
First day	73.56	35.62	7.60	2.02	25.79	28.97	64.38
Second day	82.79	27.87	9.80	1.93	32.68	27.72	72.13
Third day	80.89	29.46	9.42	2.18	20.62	38.32	70.54
Fourth day	80.10	26.85	9.01	1.87	28.00	34.27	73.15
Fifth day	79.02	25.80	9.10	1.50	29.65	33.95	74.20
Feces of steer No. 2:							
First day	82.00	29.65	7.40	1.91	36.80	24.04	70.35
Second day	83.67	27.40	8.20	1.80	27.71	34.89	72.60
Third day	80.88	28.71	8.24	1.82	26.00	35.23	71.29
Fourth day	83.13	23.84	7.13	1.76	29.18	38.09	76.16
Fifth day	83.46	28.10	7.09	1.64	31.83	31.34	71.90

TABLE 8.—*Weight of the feed, refuse, and feces in experiment No. 3, with calculated digestion coefficients of both feeds used and of each separately.*

STEER NO. 1.

	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Total prickly pear fed	33,994.7	6,374.0	1,012.0	503.1	4.154.1	21,950.4	27,620.7
Total prickly pear refused	14,236.6	2.669.4	424.3	210.7	1,739.7	9,192.6	11,567.2
Total prickly pear eaten	19,758.1	3,704.6	587.7	292.4	2,414.4	12,757.8	15,053.5
Total alfalfa fed	9,685.6	977.3	1,364.7	200.5	3,126.5	4,016.6	8,708.3
Total alfalfa refused	None.	None.	None.	None.	None.	None.	None.
Total alfalfa eaten	9,685.6	977.3	1,364.7	200.5	3,126.5	4.016.6	8,708.3
Feces:							
First day	2.164.9	771.1	164.5	43.7	558.3	627.3	1,393.8
Second day	2,592.2	722.4	254.0	50.0	847.1	718.7	1,869.8
Third day	2,062.0	607.5	194.2	45.0	425.2	790.1	1,454.5
Fourth day	2,980.0	800.1	268.5	55.7	834.4	1,021.2	2,179.9
Fifth day	3,008.5	776.2	273.8	45.1	892.0	1,021.4	2,232.3
Total feces dropped	12,807.6	3,677.3	1,155.0	239.5	3.557.0	4,178.8	9,130.3
Coefficient of digestion of prickly pear and alfalfa (per cent)	56.84	21.46	40.84	51.41	35.80	75.09	61.57
Total alfalfa undigested	4,273.3	597.6	470.1	163.4	1,865.0	1,211.4	3,675.8
Total feces from prickly pear	8,534.3	3,079.7	694.9	76.1	1,692.0	2,967.4	5,454.5
Total prickly pear digested	11,223.8	−624.9	−97.2	216.3	722.4	9,790.4	9,599.0
Coefficient of digestion of prickly pear (per cent)	56.81	−16.87	−16.54	73.97	29.92	76.74	63.09
Coefficient of digestion of alfalfa (per cent) [a]	39.35	38.90	29.76	26.54	26.65	57.04	42.24

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[a] Calculated on the assumption that the coefficient of digestion of the prickly pear used in this experiment was an average of the two varieties fed in experiments Nos. 1 and 2.

TABLE 8.—*Weight of the feed, refuse, and feces in experiment No. 3, with calculated digestion coefficients of both feeds used and of each separately*—Continued.

STEER NO. 2.

	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Total prickly pear fed	39,146.1	7,339.9	1,166.6	579.4	4,783.7	25,276.4	31,806.2
Total prickly pear refused	12,033.3	2,256.2	358.6	178.1	1,470.5	7,760.9	9,777.1
Total prickly pear eaten	27,112.8	5,083.7	808.0	401.3	3,313.2	17,506.5	22,029.1
Total alfalfa fed	10,157.3	1,024.9	1,431.2	210.2	3,278.8	4,212.2	9,132.4
Total alfalfa refused	None.	None.	None.	None.	None.	None.	None.
Total alfalfa eaten	10,157.3	1,024.9	1,431.2	210.2	3,278.8	4,212.2	9,132.4
Feces:							
First day	1,948.5	577.7	144.2	37.2	717.0	472.4	1,370.7
Second day	2,604.6	713.7	213.6	46.9	721.7	908.7	1,890.9
Third day	2,820.2	809.7	232.4	51.3	733.3	993.5	2,010.5
Fourth day	3,188.4	760.1	227.3	56.1	930.4	1,214.5	2,428.3
Fifth day	2,160.1	607.0	153.2	35.4	687.6	676.9	1,553.1
Total feces dropped	12,721.8	3,468.2	970.7	226.9	3,790.0	4,266.0	9,253.5
Coefficient of digestion of prickly pear and alfalfa (per cent)	65.87	43.22	56.65	62.89	42.51	80.36	70.34
Total alfalfa undigested	4,481.3	626.7	493.0	147.2	1,955.8	1,270.4	3,854.8
Total feces from prickly pear	8,240.5	2,841.5	477.7	79.7	1,834.2	2,995.6	5,398.7
Total prickly pear digested	18,872.3	2,242.2	189.3	321.6	1,479.0	14,510.9	16,630.4
Coefficient of digestion of prickly pear (per cent)	69.61	44.11	40.88	80.14	44.63	82.88	75.49
Coefficient of digestion of alfalfa (per cent)	68.41	80.59	60.65	52.28	37.29	78.65	64.38

EXPERIMENT NO. 4.—DIGESTIBILITY OF PRICKLY PEAR (*Opuntia engelmannii cycloides*) AND COTTON-SEED MEAL.

In the prickly-pear region of Texas a ration consisting of this feeding stuff with cotton-seed meal is very common. It is customary and better to give the cattle either the run of a dry grass pasture or some coarse feed in connection with this ration, as it will serve the double purpose of widening the too narrow ration produced from too much cotton-seed meal and tend to check the scouring which results from the use of these two feeds alone. Bulletin 74 of the Bureau of Plant Industry, United States Department of Agriculture, gives a number of rations as used by Texas stockmen and dairymen made up of prickly pear and cotton-seed meal in varying amounts that were usually fed together with other feeds. However, in the ration used in this digestion experiment prickly pear and cotton-seed meal alone were used, because it was desired not only to determine the coefficient of digestion of the ration of the two when fed together but also to use the weights obtained for a calculation of the coefficient of digestion of cotton-seed meal, and these would have been complicated by the addition of other feeds to the ration.

Steer No. 1 ate an average of 4.78 pounds of cotton-seed meal and 37.28 pounds of prickly pear daily. This made only 14.14 pounds of dry matter, which was about 1 pound short of a maintenance ration of dry matter; but the proteids were in excess of the amount required for maintenance by more than a pound, and while the carbohydrates were a trifle short the excess of both proteids and fat made the total nutrients more than the amount required for maintenance. The nutritive ratio of the feed for this steer was 1 to 4.49, and he gained 1,551.9 grams of proteids in the five days.

Steer No. 2 ate a daily average of 4.99 pounds of cotton-seed meal and 47.04 pounds of prickly pear. This gave him 17.35 pounds, or nearly 1 pound more than a maintenance ration, of dry matter which contained a slight excess of all the nutrients. The nutritive ratio of his feed was 1 to 5.52. He gained for the five days 1,262.5 grams of protein.

The digestion coefficient for the two steers agreed very closely, but while the coefficient for the protein of cotton-seed meal and of cotton-seed meal with prickly pear was about what might be expected, the coefficient for the protein in the prickly pear was a minus quantity to about the same degree for both steers. This error might be attributed to several causes. It may have been because the composite sample of pear used for analysis did not contain sufficient proteids to be representative of the prickly pear fed. It had only 2.59 per cent of protein, while an average of the five samples of this species recorded in Bulletin 60 of the New Mexico Experiment Station had 3.99 per cent, and an average of all prickly pears contained 4.47 per cent protein in the air-dry material. It is barely possible also that some error may have been introduced here by hairs from the shedding animal getting into the feces. It is also possible that it resulted from a larger amount of metabolic products formed from a feed like cotton-seed meal with its high protein content. Steer No. 1, for example, got hardly 1 pound of protein from the prickly pear during the five days, but obtained nearly 10.5 pounds from the cotton-seed meal; and the large amount of protein from the latter source may have increased the metabolic nitrogen in the feces and thus made it appear that the feces from the prickly pear contained more protein than did the feed, when in reality it may have been due in part at least to cleavage products resulting from the protein of the cotton-seed meal fed.

As a further attempt to explain these negative results Professor Spillman has suggested the very probable theory that it resulted from the reduced digestibility of the protein of the cotton-seed meal, due to the laxative action of the prickly pear forcing the other feed from the digestive tract before its protein, which digests slowly, had been thoroughly acted upon, but not before the easily digested carbohydrates had been more completely assimilated. Since cotton-seed meal is a substance rich in protein and the prickly pear is very poor in this ingredient, a very slight reduction of the digestion coefficient of the former would and did result in an apparent negative result for the latter.

The average of three digestion coefficients for cotton-seed meal as given in Bulletin 77 of the Office of Experiment Stations, United States Department of Agriculture, was used in calculating these coefficients. Since the cotton-seed meal used in this experiment was adulterated with hulls, as may be seen from the crude-fiber analysis, it may be that the figures from the above bulletin did not represent the coefficients for the meal used in the experiment. If, however, we assume the digestibility of prickly pear fed to be the same as that obtained in previous experiments, and calculate the coefficients of digestion for the nutrients of cotton-seed meal accordingly, we find them somewhat similar to those given in Bulletin 77. It is interesting to note that both of our calculations show over 100 per cent of the fat digested, which agrees with some of the results recorded in the above bulletin, and substantiates also the statement made by Jordan in his work on "The Feeding of Animals" that "pure vegetable fats and oils are quite completely emulsified and absorbed" by animals.

TABLE NO. 9.—*Experiment No. 4—Composition of the prickly pear and cotton-seed meal fed, of the refuse, and of the feces.*

[Nutrients reported water free.]

	Water.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Prickly pear, water free	72.97	21.74	2.59	2.03	11.44	62.20	78.26
Cotton-seed meal	5.09	6.68	44.25	10.02	11.02	28.03	93.32
Refuse of prickly pear, steer No. 1	....	21.89	2.85	1.25	12.26	61.75	78.11
Refuse of prickly pear, steer No. 2	....	24.87	2.85	1.51	11.38	59.39	75.13
Refuse of cotton-seed meal, steers Nos. 1 and 2	....	6.68	44.25	10.02	11.02	28.03	93.32
Feces of steer No. 1:							
First day	77.53	30.45	13.09	1.28	19.13	36.05	69.55
Second day	82.51	30.85	12.85	1.55	18.00	36.75	69.15
Third day	82.08	31.76	12.92	1.18	18.12	36.02	68.24
Fourth day	82.63	34.82	12.14	1.13	20.14	31.77	65.18
Fifth day	79.58	35.09	11.38	1.03	19.83	32.67	64.91
Feces of steer No. 2:							
First day	81.68	26.21	14.76	1.71	21.62	35.70	73.79
Second day	81.94	30.69	13.38	1.29	19.93	34.71	69.31
Third day	84.13	31.78	14.22	.97	16.93	36.10	68.22
Fourth day	82.75	36.10	9.95	1.05	22.04	30.86	63.90
Fifth day	85.15	34.70	9.86	1.06	19.45	34.93	65.30

TABLE No. 10.—*Weight of the feed, refuse, and feces in experiment No. 4, with calculated digestion coefficients of both feeds used and of each separately.*

STEER NO. 1.

	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Total prickly pear fed	29,722.2	6,461.6	709.8	603.4	3,400.2	18,487.2	23,260.6
Total prickly pear refused	7,964.5	1,743.4	227.0	99.6	976.4	4,918.1	6,221.1
Total prickly pear eaten	21,757.7	4,718.2	542.8	503.8	2,423.8	13,569.1	17,039.5
Total cotton-seed meal fed	10,758.0	718.6	4,760.4	1,078.0	1,185.5	3,015.5	10,039.4
Total cotton-seed meal refused	469.8	31.4	207.9	47.1	51.8	131.6	438.4
Total cotton-seed meal eaten	10,288.2	687.2	4,552.5	1,030.9	1,133.33	2,883.9	9,601.0
Feces—First day	2,033.5	619.2	206.2	26.0	389.0	733.1	1,414.3
Second day	2,436.8	751.8	313.1	37.8	438.6	895.5	1,685.0
Third day	1,863.7	591.9	240.8	22.0	337.7	671.3	1,271.8
Fourth day	1,544.2	537.7	187.5	17.4	311.0	490.6	1,006.5
Fifth day	2,550.5	895.0	290.2	26.3	505.8	833.2	1,655.5
Total feces dropped	10,428.7	3,395.6	1,297.8	129.5	1,982.1	3,623.7	7,033.1
Coefficient of digestion of prickly pear and cotton-seed meal (per cent)	67.46	39.03	74.53	91.56	44.28	77.97	73.60
Total cotton-seed meal undigested	2,705.8	524.3	528.1	69.1	504.3	1,136.3	2,294.6
Total feces from prickly pear[a]	7,722.9	2,871.3	769.7	60.4	1,477.8	2,487.4	4,738.5
Total prickly pear digested	14,034.8	1,846.9	−226.90	443.4	946.8	11,081.7	12,301.0
Coefficient of digestion of prickly pear (per cent)	64.50	39.01	−41.8	88.08	39.03	81.67	72.19
Coefficient of digestion of cotton-seed meal (per cent)[b]	72.84	47.42	77.51	102 7	37.04	64.83	75.09

STEER NO. 2.

	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
Total prickly pear fed	35,878.3	7,799.9	929.2	728.3	4,104.5	22,316.4	28,078.4
Total prickly pear refused	7,279.1	1,810.3	207.5	109.9	828.4	4,323.0	5,468.8
Total prickly pear eaten	28,599.2	5,988.6	721.7	618.4	3,276.1	17,993.4	22,609.6
Total cotton-seed meal fed	10,758.0	718.6	4,760.4	1,078.0	1,185.5	3,015.6	10,039.5
Total cotton-seed meal refused	20.9	1.4	9.2	2.1	2.3	5.9	19.5
Total cotton-seed meal eaten	10,737.1	717.2	4,751.2	1,075.9	1,183.2	3,009.7	10,020.0
Feces—First day	1,296.1	339.7	191.3	22.2	280.2	462.7	956.4
Second day	2,975.4	913.2	398.1	38.4	593.0	1,032.7	2,062.2
Third day	2,487.6	790.6	353.7	24.1	421.2	898.0	1,697.0
Fourth day	3,073.1	1,109.4	305.8	32.3	677.3	948.3	1,963.7
Fifth day	2,690.1	933.5	265 2	28.5	523.2	939.7	1,756.6
Total feces dropped	12,522.3	4,086.4	1,514.1	145.5	2,494.9	4,281.4	8,435.9
Coefficient of digestion of prickly pear and cotton-seed meal (per cent)	68.17	39.05	72.33	91.41	44.05	77.97	74.15

[a] Calculated on the assumption that the digestibility of this variety of cactus was the average of the two fed in experiments Nos. 1 and 2.

[b] Coefficient of digestion for cotton-seed meal used in these calculations was taken from Bulletin 77, Office of Experiment Stations, United States Department of Agriculture.

Table No. 10.—*Weight of the feed, refuse, and feces in experiment No. 4, with calculated digestion coefficients of both feeds used and of each separately*—Continued.

STEER NO. 2—Continued.

	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Average coefficient of digestion of prickly pear and cotton-seed meal	67.82	39.04	73.43	91.49	44.17	77.97	73.88
Total cotton-seed meal undigested	2,823.9	547.2	551.1	72.1	526.5	1,185.8	2,394.8
Total feces from prickly pear[a]	9,608.4	3,539.2	963.0	73.4	1,968.4	3,095.6	6,041.1
Total prickly pear digested	18,900.8	2,449.4	−241.3	545.0	1,307.7	14,897.8	16,568.5
Coefficient of digestion of prickly pear (per cent)	66.08	40.90	−34.82	88.13	39.92	82.79	73.28
Average coefficient of digestion of prickly pear (per cent)	65.29	39.96	−38.31	88.11	39.48	82.23	72.74
Coefficient of digestion of cotton-seed meal (per cent)[b]	76.88	67.22	69.89	104.6	34.06	72.71	77.28

[a] Calculated on the assumption that the digestibility of this variety of cactus was the average of the two fed in experiments Nos. 1 and 2.

[b] Coefficient of digestion for cotton-seed meal used in these calculations was taken from Bulletin 77, Office of Experiment Stations, United States Department of Agriculture.

EXPERIMENT NO. 5.—DIGESTIBILITY OF A FAIR QUALITY OF SECOND-CUT ALFALFA.

This experiment was made to determine the digestion coefficients of the alfalfa that was used in experiment No. 3. The results are given in Table 12, from which it will be seen that the coefficients obtained in this experiment are about the same as those determined by other experiment stations. For some of the nutrients the coefficient is somewhat less than was obtained elsewhere. This may be accounted for by the fact that the hay used had lost a considerable proportion of its leaves in curing, and the Colorado Experiment Station has shown that these are the most digestible portions of the plant.

The dry matter eaten per day was somewhat less than a maintenance ration. The proteids were far in excess of the amount required, yet steer No. 2 lost, and steer No. 1 gained only a small amount of this nutrient, which shows that the excess of proteids was evidently used to serve the function of carbohydrates.

Table 11.—*Experiment No. 5—Composition of the alfalfa fed, of the refuse, and of the feces.*

[Nutrients reported water free.]

	Water.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Alfalfa as fed	5.09	9.58	13.37	1.96	30.64	39.36	85.33
Alfalfa, water free	....	10.09	14.09	2.07	32.28	41.47	89.91
Refuse, water free, steer No. 1	....	10.09	14.09	2.07	32.28	41.47	89.91
Refuse, water free, steer No. 2	....	10.09	14.09	2.07	32.28	41.47	89.91

TABLE 11.—*Experiment No. 5—Composition of the alfalfa fed, of the refuse, and of the feces*—Continued.

	Water.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Feces of steer No. 1:							
First day	78.27	13.31	11.50	2.17	44.52	28.50	86.69
Second day	78.09	11.35	10.53	2.11	42.73	33.28	88.65
Third day	75.75	14.11	10.68	2.52	45.06	27.63	85.89
Fourth day	78.98	15.80	10.67	3.00	41.19	29.34	84.20
Fifth day	77.24	10.55	11.74	3.16	42.02	32.53	89.45
Feces of steer No. 2:							
First day	84.87	16.15	11.57	2.26	43.68	26.34	83.88
Second day	88.56	13.19	10.72	3.18	46.67	26.24	86.81
Third day	80.97	15.56	10.63	3.37	42.56	27.88	84.44
Fourth day	81.82	15.41	11.57	3.51	43.37	26.14	84.59
Fifth day	74.99	13.61	10.63	3.36	46.54	25.86	86.39

TABLE 12.—*Weight of the feed, refuse, and feces in experiment No. 5, with the calculated digestion coefficient.*

STEER NO. 1.

	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Total alfalfa fed	32,274.1	3,256.5	4,547.4	668.1	10,418.1	13,384.0	29,017.6
Total refused	121.1	12.2	17.1	2.5	39.1	29.1	87.8
Total eaten	32,153.0	3,244.3	4,530.3	665.6	10,479.0	13,384.9	28,929.8
Feces:							
First day	2,162.1	287.8	248.6	46.9	962.6	616.2	1,874.3
Second day	2,952.4	335.1	310.9	62.3	1,261.6	982.5	2,617.3
Third day	2,934.3	414.0	313.4	73.9	1,322.2	810.8	2,520.3
Fourth day	2,979.6	470.8	317.9	89.4	1,227.3	874.2	2,508.8
Fifth day	2,981.6	314.6	350.0	94.2	1,252.9	969.9	2,667.0
Total feces dropped	14,010.0	1,822.3	1,540.8	366.7	6,026.6	4,253.6	12,187.7
Total digested	18,143.0	1,422.0	2,989.5	298.9	4,452.4	9,101.3	16,742.1
Coefficient of digestion (per cent)	56.43	43.83	65.99	44.91	42.49	68.15	57.87

STEER NO. 2.

	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
Total alfalfa fed	32,274.1	3,256.5	4,547.4	668.1	10,418.1	13,384.0	29,017.6
Total refused	None.	None.	None.	None.	None.	None.	None.
Total eaten	32,274.1	3,256.5	4,547.4	668.1	10,418.1	13,384.0	29,017.6
Feces:							
First day	2,258.2	364.7	261.3	51.0	986.4	594.8	1,893.5
Second day	1,947.1	256.8	208.7	61.9	908.7	511.0	1,690.3
Third day	2,816.4	438.2	299.4	94.9	1,198.7	785.2	2,378.2
Fourth day	3,245.1	0.1	375.5	113.9	1,407.4	848.2	2,745.0
Fifth day	4,150.4	564.9	441.2	139.5	1,931.6	1,073.2	3,585.5
Total feces dropped	14,417.2	2,124.7	1,586.1	461.2	6,432.8	3,812.4	12,292.5
Total digested	17,856.9	1,131.8	2,961.3	206.9	3,985.3	9,571.6	16,725.1
Coefficient of digestion (per cent)	55.33	34.75	65.12	30.97	38.20	71.52	57.63
Average coefficient of digestion (per cent)	55.88	39.29	65.56	37.94	40.35	69.84	57.75

EFFECT OF PRICKLY PEAR ON THE DIGESTIBILITY OF OTHER FEEDING STUFFS.

From Table 13 it may be seen that in feeding a mixed ration of prickly pear and alfalfa, or prickly pear and cotton-seed meal, the general effect is to increase the digestibility of all three feeds. This table shows an increase in the digestible dry matter of all three, and with some exception there is an increase in the digestibility of the nutrients in them all.

If the ration of prickly pear will increase the digestibility of all feeding stuffs, as it apparently has that of alfalfa and cotton-seed meal, then this feed has a greater value than is shown by its own digestible nutrients. The probabilities are that the addition of this green and succulent feed to any dry feeding stuff will increase the digestibility of both.

TABLE 13.—*Average digestibility of prickly pear, alfalfa, and cotton-seed meal, and of a mixed ration of alfalfa and prickly pear, and cotton-seed meal and prickly pear.*

	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Prickly pear alone	64.91	35.69	49.56	68.46	47.66	80.77	72.76
Alfalfa alone	55.88	39.29	65.56	37.94	40.35	69.84	57.75
Cotton-seed meal alone	73.70	23.70	88.40	93.30	55.50	60.60	76.10
Alfalfa and prickly pear	68.41	80.59	60.65	52.28	37.27	78.65	64.38
Cotton-seed meal and prickly pear	74.86	57.32	73.70	103.70	35.55	68.77	76.19

TABLE 14.—*Summary of all digestion coefficients obtained in these experiments, together with some coefficients of alfalfa and cotton-seed meal as determined elsewhere.*

Feed.	Steer No.	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Prickly Pear (*Opuntia lindheimeri*)	1	67.12	37.46	59.03	67.42	41.31	83.40	71.21
Do	2	64.61	33.67	57.47	68.38	41.32	81.78	77.03
Average		65.86	35.57	58.25	67.90	41.32	82.59	74.12
Prickly pear (*O. lævis?*)	1	65.52	38.88	39.43	69.18	55.96	79.87	72.55
Do	2	62.40	32.74	42.31	68.86	51.02	78.03	70.12
Average		63.96	35.81	40.87	69.02	53.99	78.95	71.39
Averages of both above averages		64.91	35.69	49.56	68.46	47.66	80.77	72.76
Prickly pear, calculated from feed of prickly pear and alfalfa	[a]1	56.81	−16.87	−16.54	73.97	29.92	76.74	63.09
Do	2	69.61	44.11	40.88	80.14	44.63	82.88	75.49
Prickly pear, calculated from feed of prickly pear and cotton-seed meal	1	64.50	39.01	−41.89	88.08	39.03	81.67	72.19
Do	2	65.29	39.96	−38.31	88.11	39.48	82.23	72.74
Average		64.90	39.49	−40.60	88.10	39.26	81.95	72.47

[a] The digestion coefficients obtained from steer No. 1 that was fed a ration of prickly pear and alfalfa are all evidently too low and should not be used in the preparation of rations from either prickly pear, alfalfa, or the mixed feed.

TABLE 14.—*Summary of all digestion coefficients obtained in these experiments, together with some coefficients of alfalfa and cotton-seed meal as determined elsewhere*—Con.

Feed.	Steer No.	Dry matter.	Ash.	Protein.	Fat.	Crude fiber.	Nitrogen-free extract.	Organic matter.
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Prickly pear and alfalfa	[a] 1	56.84	21.46	40.84	51.41	35.80	75.09	61.57
Do	2	65.87	43.22	56.65	62.89	42.51	80.36	70.34
Average	......	61.36	32.34	48.75	57.15	39.16	77.73	65.96
Prickly pear and cotton-seed meal	1	67.46	39.03	74.53	91.56	44.28	77.97	73.60
Do	2	68.17	39.05	72.33	91.41	44.05	77.97	74.15
Average	......	67.82	39.04	73.43	91.49	44.17	77.97	73.88
Alfalfa alone	1	56.43	43.83	65.99	44.91	42.49	68.15	57.87
Do	2	55.33	34.75	65.12	30.97	38.20	71.52	57.63
Average	......	55.88	39.29	65.56	37.94	40.35	69.84	57.75
Alfalfa when fed with prickly pear	[a] 1	39.35	38.90	29.76	26.54	26.65	57.04	42.24
Do	2	68.41	80.59	60.65	52.28	37.29	78.65	64.38
Average	......	53.88	59.75	45.21	39.41	31.97	67.85	53.31
Alfalfa, Colorado Experiment Station	......	63.95	57.67	72.54	29.86	49.93	72.89	....
Alfalfa:[b]								
Maximum	......	60.20	40.90	77.00	54.00	49.00	71.80	....
Minimum	......	57.00	38.00	68.80	48.40	43.30	64.00	....
Average	......	58.90	39.50	72.00	51.00	46.00	69.20	....
Alfalfa, Minnesota Experiment Station	......	65.84	51.48	75.38	55.88	57.57	71.86	....
Alfalfa, Kansas Experiment Station:								
First cut	......	59.40	63.49	78.52	60.00	46.10	75.31	....
Second cut	......	58.25	56.41	75.14	30.39	50.44	71.99	....
Third cut	......	60.03	60.90	76.70	51.65	50.63	75.24	....
Alfalfa, Utah Experiment Station	......	60.16	40.85	70.30	50.57	45.67	71.80	....
Cotton-seed meal:[b]								
Maximum	......	83.90	38.00	96.10	103.20	100.00	71.00	87.00
Minimum	......	65.00	3.00	83.50	87.30	19.50	43.80	69.10
Average	......	73.70	23.70	88.40	93.30	55.50	60.60	76.10
Cotton-seed meal from feed of cotton-seed meal with prickly pear	1	72.84	47.42	77.51	102.7	37.04	64.83	75.09
Do	2	76.88	67.22	60.89	104.6	34.06	72.71	77.28
Average	......	74.86	57.32	73.70	103.7	35.55	68.77	76.19

[a] The digestion coefficients obtained from steer No. 1 that was fed a ration of prickly pear and alfalfa are all evidently too low and should not be used in the preparation of rations from either prickly pear, alfalfa, or the mixed feed.

[b] Bulletin 77, Office of Experiment Stations, United States Department of Agriculture.

Table 15.—*Daily rations fed during the five digestion periods, and a maintenance ration for each steer calculated from Wolff's feeding standard for oxen at rest in stalls.*

STEER NO. 1.

Experiment No.	Feed.	Digestible organic matter.					Nutritive ratio.
		Dry matter.	Protein.	Carbohydrates.	Fat.	Total nutrients.	
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	
1	Prickly pear (*Opuntia lindheimeri*)	13.84	0.42	7.44	0.13	8.00	1:18.23
2	Prickly pear (*O. lævis?*)	6.64	.11	3.57	.08	3.76	1:33.56
3	Prickly pear and alfalfa	12.99	.35	6.48	.11	6.94	1:19.13
4	Prickly pear and cotton-seed meal	14.14	1.68	6.13	.62	8.43	1: 4.49
5	Alfalfa	14.19	1.31	5.98	.11	7.40	1: 4.75
	Maintenance ration	15.10	.60	6.90	.13	7.66	1:12
	STEER NO. 2.						
1	Prickly pear (*Opuntia lindheimeri*)	12.98	0.40	6.98	0.13	7.50	1:18.23
2	Prickly pear (*O. lævis?*)	9.36	.16	5.02	.11	5.29	1:33.04
3	Prickly pear and alfalfa	16.44	.56	8.93	.17	9.66	1:16.65
4	Prickly pear and cotton-seed meal	17.35	1.75	8.09	.68	10.52	1: 5.52
5	Alfalfa	14.23	1.32	5.98	.11	7.40	1: 4.74
	Maintenance ration	16.70	.67	7.65	.14	8.43	1:12

Table 16.—*Weight of feed eaten, feces and urine excreted, and water drunk during the five digestion periods.*

Experiment No.	Steer No.	Feed.	Weight of feed for five days.		Average weight of feed per day.		Weight of feces for five days.	
			Grams.	Pounds.	Grams.	Pounds.	Grams.	Pounds.
[a] 1	1	Prickly pear (*Opuntia lindheimeri*)	187,539	413.63	46,884.75	103.41	62,766	138.43
	2	Prickly pear (*O. lindheimeri*)	179,314	395.48	44,828.5	98.87	58,591	129.23
2	1	Prickly pear (*O. lævis?*)	121,322	267.58	2,426.44	53.52	20,293	44.75
	2	Prickly pear (*O. lævis*)	163,630	360.89	32,726	72.18	38,896	85.79
3	1	Prickly pear	95,580	210.81	19,116	42.16	....	....
		Alfalfa	10,205	22.51	2,041	4.50	....	....
		Total	105,785	233.32	21,157	46.66	63,355	139.73
	2	Prickly pear	129,627	285.89	25,925.4	57.18	....	....
		Alfalfa	10,702	23.60	2,140.4	4.72	....	....
		Total	140,329	309.49	28,065.8	61.90	73,485	162.07
4	1	Prickly pear	84,498	186.36	16,899.8	37.27	....	....
		Cotton-seed meal	10,845	23.92	2,169.0	4.78	....	....
		Total	95,343	210.28	19,068.8	42.05	54,605	120.43
	2	Prickly pear	106,645	235.21	21,329.0	47.04	....	....
		Cotton-seed meal	11,318	24.96	2,263.6	4.99	....	....
		Total	117,963	260.17	23,592.6	52.03	75,155	165.76
5	1	Alfalfa	339,922.4	749.72	67,984.5	149.94	62,800	138.51
	2	Alfalfa	340,050	750.0	68,010.0	150.0	81,190	179.07

[a] This experiment lasted for a period of four days only.

TABLE 16.—*Weight of feed eaten, feces and urine excreted, and water drunk during the five digestion periods*—Continued.

Experiment No.	Steer No.	Feed.	Average weight of feces per day.		Weight of urine for five days.		Average weight of urine per day.	
			Grams.	Pounds.	Grams.	Pounds.	Grams.	Pounds.
[a]1	1	Prickly pear (*Opuntia lindheimeri*)	15,691.5	34.61	51,981	114.65	12,995.2	28.66
	2	Prickly pear (*O. lindheimeri*)	14,647.75	32.31	38,915	85.83	9,728.75	21.46
2	1	Prickly pear (*O. lævis?*)	4,058.6	8.95	26,874	59.27	5,374.8	11.85
	2	Prickly pear (*O. lævis*)	7,779.2	17.16	50,848	112.15	10,169.6	22.43
3	1	Prickly pear						
		Alfalfa						
		Total	12,671	27.94	31,700	69.92	6,340	13.98
	2	Prickly pear						
		Alfalfa						
		Total	14,697	32.41	42,222	93.12	8,444.4	18.62
4	1	Prickly pear						
		Cotton-seed meal						
		Total	10,921	24.09	28,975	63.91	5,795	12.78
	2	Prickly pear						
		Cotton-seed meal						
		Total	15,031	33.15	37,525	82.76	7,505	16.55
5	1	Alfalfa	12,560	27.70	44,785	98.77	8,959	19.75
	2	Alfalfa	16,238	35.81	43,910	96.84	8,782	19.37

Experiment No.	Steer No.	Feed.	Weight of water drunk for five days.		Average weight of water per day.	
			Grams.	Pounds.	Grams.	Pounds.
[a]1	1	Prickly pear (*Opuntia lindheimeri*)	None.	None.	None.	None.
	2	Prickly pear (*O. lindheimeri*)	None.	None.	None.	None.
2	1	Prickly pear (*O. lævis?*)	17,225	37.99	3,445	7.60
	2	Prickly pear (*O. lævis*)	12,275	27.07	2,455	5.41
3	1	Prickly pear				
		Alfalfa				
		Total	41,263	91.01	8,252.6	18.2
	2	Prickly pear				
		Alfalfa				
		Total	43,240	95.37	8,648	19.07
4	1	Prickly pear				
		Cotton-seed meal				
		Total	66,700	147.11	13,340	29.42
	2	Prickly pear				
		Cotton-seed meal				
		Total	83,475	184.11	16,695	36.82
5	1	Alfalfa	106,480	234.86	21,296	46.97
	2	Alfalfa	110,980	244.77	22,196	48.95

[a] This experiment lasted for a period of four days only.

INCOME AND OUTGO OF NITROGEN.

In Table 17 is given the income and outgo of nitrogen for both steers during the five digestion periods. The gain or loss of nitrogen is the difference between the amount taken into the animal as food and the sum of that which is excreted in the feces and urine.

It is interesting to note that in the first digestion period, when the steers were fed prickly pear (*Opuntia lindheimeri*) alone which had a nutritive ratio of 1 to 18.23, they each gained nearly 1 pound of proteids in the four days. Steer No. 1, for example, ate 1,322.8 grams (2.9 pounds) of protein and gained 453.1 grams (1 pound) or 34.26 per cent.

Prickly pear alone was the ration also for the second period, but in this experiment a different species was used, as well as different steers, and the latter were fat from a previous grain ration and not accustomed to eating prickly pear. Analysis shows that the feed from this species of prickly pear has about 1 per cent less protein than the species fed in the first period. The steers ate only about half the ration eaten by the steers for the first period and digested about 18 per cent less of the protein. As a consequence the nutritive ratio in this feed was 1 to 33 for both steers, and each lost over one-half pound of protein, or nearly 50 per cent of that eaten during their five-day digestion period. Steer No. 1, for example, consumed 99.2 grams and excreted 146.1 grams of nitrogen in the five days, making a loss of 293.1 grams (0.65 pound) of protein, or 47.28 per cent. In the third digestion period steer No. 1 ate 42.16 pounds of prickly pear and 4.5 pounds of alfalfa daily, while steer No. 2 ate 57.18 pounds and 4.72 pounds of alfalfa. Something went wrong in this experiment with either steer No. 1 or our analyses, we can not say which, although fairly closely agreeing duplicate determinations were secured in all the analyses. Table 17 shows a low digestion coefficient by this steer for all the nutrients. This animal consumed 312.4 grams of nitrogen for the five days, and excreted 346.5 grams, making a loss of 213.1 grams of protein, or 10.9 per cent of the nitrogen consumed. There was excreted in the urine 51.76 per cent, while with steer No. 2, on practically the same ration, only 28.16 per cent of the nitrogen was in the urine.

The results obtained with steer No. 2 were more satisfactory throughout. He showed a normal digestion coefficient for all the nutrients, but it was hardly enough for the proteids to make a theoretical maintenance ration for him; yet we find a daily gain in Table 17 of 127.6 grams of this nutrient.

There was a quite uniform gain of nitrogen for both steers during the fourth digestion period in which prickly pear and cotton-seed meal composed the ration. The gain for steer No. 1 amounted to 30.46 per cent, and for steer No. 2, 23.07 per cent.

Fifteen pounds of alfalfa per day was the ration for both steers during the fifth period. The digestion coefficient for the two was close enough to make a nutritive ratio for both of 1 to 4.75.

From Table 15 it may be seen that steer No. 1 digested or retained in his system 1.31 pounds, and No. 2, 1.32 pounds of protein during this period. According to Wolff's standard for oxen at rest in stalls these figures are 0.71 pound for steer No. 1 and 0.65 pound for steer No. 2 in excess of the amount required for maintenance; yet we find that during the five days steer No. 1 gained only 302.5 grams (0.66 pound) of protein, and steer No. 2 actually lost 222.5 grams (0.5 pound). Why there should be such a slight gain of protein for steer No. 1 and a loss for No. 2 when the proteids actually digested by both were far in excess of the estimated amount required we are at a loss to say. It may be explained, however, by the supposition that because of the narrow nutritive ratio of the feed neither steer had a maintenance ration of nonproteids, and to supply the necessary energy their bodies broke down the proteids and used the nonnitrogenous part of the molecule, excreting the nitrogenous portion produced from the cleavage through the kidneys. That such is the case would seem to be shown by the fact that steer No. 2, for example, in consuming 727.6 grams (1.6 pounds) of nitrogen excreted 509.4 grams (1.1 pounds) or 70.01 per cent in the urine.

TABLE 17.—*Income and outgo of nitrogen during the five digestion periods.*

Experiment No.	Feed.	Steer No.	Nitrogen in urine.	Nitrogen in feces.	Total nitrogen excreted.	Total nitrogen eaten.	Nitrogen (gain, +; loss, −).
			Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1	Prickly bear (*Opuntia lindheimeri*)...	1	52.5	86.6	139.1	211.6	+ 72.5
		2	47.1	84.4	131.5	198.4	+ 66.9
2	Prickly pear. (*O. lævis?*)...............	1	86.0	60.1	146.1	99.2	− 46.9
		2	121.5	81.7	203.2	140.0	− 63.2
3	Prickly pear (*O. engelmannii cycloides*) and alfalfa.....................	1	161.7	184.8	346.5	312.4	− 34.1
		2	100.9	155.3	256.2	358.3	+102.1
4	Prickly pear (*O. engelmannii cycloides*) and cotton-seed meal...........	1	359.3	207.7	567.0	815.3	+248.3
		2	431.5	242.2	673.7	875.7	+202.0
5	Alfalfa..................................	1	430.0	246.5	676.5	724.9	+ 48.4
		2	509.4	253.8	763.2	727.6	− 35.6

Experiment No.	Feed.	Steer No.	Proteids (gain, +; loss, −).	Nitrogen (gain, +; loss, −).	Excreted nitrogen in feces.	Excreted nitrogen in urine.
			Grams.	*Per cent.*	*Per cent.*	*Per cent.*
1	Prickly pear (*Opuntia lindheimeri*)......	1	+ 453.1	+34.26	40.93	24.82
		2	+ 418.1	+33.72	42.54	23.74
2	Prickly pear (*O. lævis ?*)...............	1	− 293.1	−47.28	60.58	86.69
		2	− 395.0	−45.14	58.35	86.79
3	Prickly pear (*O. engelmannii cycloides*) and alfalfa..............................	1	− 213.1	−10.92	59.15	51.76
		2	+ 638.1	+28.50	43.34	28.16
4	Prickly pear (*O. engelmannii cycloides*) and cotton-seed meal..................	1	+1,551.9	+30.46	25.47	54.09
		2	+1,262.5	+23.07	....	49.16
5	Alfalfa..	1	+ 302.5	+ 6.68	34.00	59.32
		2	− 222.5	− 4.89	34.88	70.01

CONCLUSIONS.

(1) The average digestibility of the nutrients of prickly pear as determined in the first experiment where *Opuntia lindheimeri* was used were: Dry matter, 65.86 per cent; ash, 33.68 per cent; protein, 57.47 per cent; fat, 68.38 per cent; crude fiber, 41.32 per cent; nitrogen-free extract, 81.78 per cent.

In the second experiment where the variety *O. lævis?* was used the coefficients of digestion were: Dry matter, 63.96 per cent; ash, 35.81 per cent; protein, 40.87 per cent; fat, 69.02 per cent; crude fiber, 53.99 per cent; nitrogen-free extract, 78.95 per cent.

In general these results would perhaps show a somewhat low coefficient for protein, a decidedly low coefficient for ash, but a very high coefficient for the nitrogen-free extract. The total digestible nutrients are about equal to those of immature green corn fodder.

(2) Our experiments seem to show that when prickly pear is fed with cured fodders or grains the digestibility of both is increased. For this reason prickly pear has a greater food value than is shown by its analysis and digestion coefficients.

(3) The nutritive ratio, i. e., the ratio of proteids to carbohydrates, is very wide for this feed, and in feeding it to all classes of animals, for whatever purpose, much better results should be obtained when it is fed with some substance of a high protein content.

(4) While the digestibility of the ash was apparently small, as noted above, yet the large amount of ash contained in these plants caused more ash to be assimilated from a ration equivalent to 15 pounds of dry matter than is ordinarily assimilated from an equal ration of alfalfa, which has a higher coefficient of digestion for its ash.

(5) The steers seldom drank water when fed prickly pear alone. In fact, in feeding a ration of 100 pounds of this feed per day the animals obtained from the feed over 8 gallons of water, which is more than was usually drunk by them when fed cured fodders alone.

(6) While no digestion experiments were made with any of the cacti other than prickly pear, the digestion coefficients of the latter could probably be safely used for all other members of this family, since their composition and other characteristics are similar.

(7) It may be seen that both steers gained proteids during the first experiment, although both ate a smaller quantity of dry matter which contained less proteids than are required according to Wolff's standard ration for oxen of their weight at rest in stalls.

In the second experiment both animals lost proteids, but here steer No. 1 ate less than half of what was eaten by steer No. 1 in the first experiment, and steer No. 2 ate over 3 pounds less than steer No. 2 of experiment No. 1.

(8) Animals scour quite badly when fed prickly pear alone; besides, other feeds are needed to supply the proper amount of proteids; and for these reasons it is better not to feed it alone.

A ration for a 1,000-pound milch cow of 50 pounds of prickly pear, 10 pounds of wheat bran, and 10 pounds of alfalfa would furnish about the correct theoretical amount of nutrients, in which the ratio of proteids to carbohydrates would be 1 to 5.46.

Issued July 17, 1908.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 107.

A. D. MELVIN, CHIEF OF BUREAU.

THE ANALYSIS OF COAL-TAR CREOSOTE AND CRESYLIC ACID SHEEP DIPS.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., April 13, 1908.

Sir: I have the honor to transmit herewith and to recommend for publication as a bulletin of this Bureau the accompanying manuscript entitled "The Analysis of Coal-tar Creosote and Cresylic Acid Sheep Dips," by Robert M. Chapin, assistant chemist in the Biochemic Division.

The Department, in accordance with Bureau of Animal Industry Order 143, sanctions the use of certain classes of preparations for the official dipping of sheep and cattle. A large number of dips are manufactured and used throughout the country, and samples are constantly being submitted to the Department for the purpose of having their use permitted in official dipping, the analytical work as a basis for passing on them being performed in the Biochemic Division of this Bureau.

This paper deals with methods of determining the various constituents of dips prepared from coal-tar derivatives. It has become of some importance to find methods of analysis which shall be sufficiently accurate and at the same time not make excessive demands upon the skill or time of the analyst, and the methods proposed in the paper appear to be comparatively simple and considerably more accurate than those heretofore employed. They should accordingly be useful to persons concerned in the examination and production of such dips, and are expected to assist manufacturers in meeting the Department's requirements.

Respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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THE ANALYSIS OF COAL-TAR CREOSOTE AND CRESYLIC ACID SHEEP DIPS.

INTRODUCTORY.

The Department of Agriculture at present sanctions the use of properly constituted coal-tar creosote and cresylic acid preparations, commonly termed "dips," for the official dipping of sheep for the cure of scabies. The proprietor of each dip must, however, fulfill certain requirements in order that the use of his product may be permitted in official dipping, involving the submission of a sample to the Department for examination.[a] The Biochemic Division of the Bureau of Animal Industry has accordingly been obliged to examine a large number of these compounds and to confront the problem of finding analytical methods of considerable accuracy which would yet not make excessive demands upon the skill or time of the analyst. While these substances have, of course, afforded a field for investigation by a number of different workers, so far as known no other laboratory has been compelled to make their detailed examination such a matter of routine. Accordingly the methods here applied may be of interest to others who have occasion to examine these or similar compounds, as well as to manufacturers.

COAL-TAR CREOSOTE DIPS.

These dips are quite simply made by dissolving rosin in phenol-bearing coal-tar oils, adding an aqueous solution of caustic soda and applying a moderate degree of heat until saponification is complete. The undiluted dip should be a clear, uniform liquid, showing no separation of its constituents. When properly diluted with a considerable quantity of water there results a permanent, uniform emulsion, from which, on standing, no oily layer or globules should separate either at top or bottom.

The completed dip will contain, then, the following substances: (1) Coal-tar hydrocarbons, (2) phenols, (3) pyridin and other volatile bases contained in coal-tar oils, (4) rosin acids, (5) soda (Na_2O), (6) water. In special cases certain other substances may be looked for. The rosin acids and soda will be present in approximately equivalent proportions in combination as a rosin soap. To the latter substance is due the power of the dip to form a perfect emulsion when diluted with water.

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[a] Bureau of Animal Industry Order 143.

CURRENT METHODS OF ANALYSIS.

Methods of analysis heretofore employed may be classified into (*a*) commercial and (*b*) scientific.

The commercial methods aim at quick results and assume that the hydrocarbons and phenols alone need be determined, since they are the essential ingredients of the dip. A measured or weighed amount is shaken with aqueous sulphuric acid, the separated aqueous layer is run off, and the residual oily portion is poured into a fractionating flask and distilled into a graduated cylinder until rosin begins to decompose, as shown by the character of the vapors and the distillate. The distillate will then supposedly contain all the phenols and all the coal-tar hydrocarbons except a slight amount remaining in the flask, which, however, is in a measure balanced by a small amount of rosin oil in the distillate. After taking the volume and specific gravity of the distillate in the cylinder, strong aqueous caustic soda is introduced; the cylinder is then stoppered and thoroughly shaken. Phenols will be taken up by the caustic soda, and will be contained in the alkaline aqueous layer which separates after the cylinder has stood some time. The volume of hydrocarbons in the amount of dip taken may then be read directly, and the volume of phenols may be obtained by difference or by noting the increase in volume of the soda solution.

The process undoubtedly undergoes some modifications in the hands of different workers, but the foregoing is a general outline of a class of methods which are apparently used considerably by commercial chemists, judging from information which has come to the Biochemic Division from several different sources.

The scientific methods follow in general the system given by Allen.[a] Fifty grams of dip are shaken with ether and aqueous sulphuric acid. Bases are removed in the aqueous layer, which is then treated with excess of sodium hydroxid, and the volatile bases are distilled off with steam and determined in the distillate by titration with standard acid and methyl orange. The ethereal portion is shaken with aqueous caustic soda, which removes phenols and rosin acids, leaving in ethereal solution hydrocarbons which are weighed after expulsion of ether. The alkaline aqueous solution of phenols and rosin acids is acidified with sulphuric acid, and the phenols are distilled over with steam and determined in the distillate by any suitable method. The distillation flask containing the rosin acids is cooled, the rosin acids are separated by ether and, after expulsion of ether, weighed. Soda is determined by ignition of a small portion of the dip in a crucible, either to sodium carbonate or, with addition of sulphuric acid, to sodium sulphate.

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[a] Allen, A. H., Commercial Organic Analysis, 3d ed., Vol. II, Pt. II, p. 262. 1901.

CRITICISM OF METHODS.

The commercial method of analysis, while rapid, contains some serious sources of error. Obviously a little of the phenols is lost in the acid aqueous extract. Moreover, practically all dips contain more or less voluminous insoluble carbonaceous matter, which conduces to the formation of an emulsion at the junction of the two layers in the separating funnel. Loss of hydrocarbons and phenols results if this emulsion is run off, while if allowed to remain with the oily layer, water together with sulphur dioxid or hydrogen sulphid will pass into the distillate, all of which tend to increase unduly the volume of hydrocarbons and phenols when the latter are measured. It is also difficult to decide exactly when to stop distillation, particularly in those dips containing oils of very high boiling point. In any case the distillate will contain some rosin oil, while some coal-tar oil will be left behind with the rosin, the relative amounts of which will vary according to the individual judgment of the analyst and will depend to a considerable extent upon the character and proportions of rosin and coal-tar oil in the particular dip under examination.

But the most serious source of error, and the one which by itself renders the method utterly untrustworthy, is the fact that undecomposed rosin is distilled along with the hydrocarbons and phenols. This rosin, which in dips containing much oil of high boiling point may amount to several grams, is of course taken up by the aqueous caustic soda with which the distillate is shaken, and will consequently cause the amount of phenols to appear several per cent too high. Nor is the presence of rosin in the distillate due to carrying the distillation too far. To decide this point dips were distilled as described, and the distillate was collected in six to eight fractions. Each fraction was treated according to the scientific method for the separation of hydrocarbons, phenols, and rosin. The results showed that rosin began to come over soon after 200° C. had been reached, and continued to appear in increasing quantity, while the distillation of phenols is certainly not complete at 250° C. It appears, therefore, utterly useless to attempt to develop any accurate method of analysis along these lines.

The scientific method, though far superior to the commercial in accuracy, possesses many disadvantages. As is well known, hydrocarbons are considerably soluble in aqueous sodium resinate and sodium cresylate, while both of these latter salts, particularly cresylates, are readily hydrolyzed, and yield notable amounts of their acids to ether. Hence many extractions and reextractions are necessary to obtain anything like a complete separation of hydrocarbons from rosin and phenols, and the process requires much time and much ether. Moreover, it is often impossible to obtain a satisfactory result on weighing the hydrocarbons because their volatility renders it difficult to free them completely from ether and moisture without undue loss. Many dips contain a certain percentage of light oils, and obviously results may then be far from the truth. Petroleum ether, with the accompanied use of alcohol, offers no advantages in the operation of extraction, and renders the final weight of hydrocarbons still more uncertain.

METHODS OF ANALYSIS ADOPTED BY THE BUREAU.

In deciding upon an official method of analysis it was desirable to adopt one that would not depend largely upon the individual judgment of the analyst, but would give definite and concordant results when the same sample was handled by different operators, and these results should closely approximate the truth. It is evident that the scientific method just referred to is far from satisfactory in this respect. It is also evident that no method which involves separation of the hydrocarbons and the determination of their weight can yield results free from suspicion. For the other ingredients of these dips workable methods have been found which attain reasonable accuracy and give concordant results in the hands of any chemist of ordinary ability with a little practice, and which do not make excessive demands upon time nor require expensive chemicals. It has seemed best, therefore, to determine these other ingredients, to subtract the total of the percentages so obtained from 100, and to call the remainder " hydrocarbons."

The following methods are accordingly those now employed in the laboratories of the Biochemic Division. The dip is well shaken before weighing, and the latter operation is most conveniently performed by pouring into a beaker somewhat more than the amount needed, balancing on the scales, and pouring off the desired amount into the receptacle to be used in the analysis.

DETERMINATION OF WATER.

Fifty grams of dip is weighed into a 100 c. c. fractionating flask with a moderately high side tube, beyond the exit of which the neck should continue for not more than one inch, and the flask is connected with a small water-cooled condenser and carefully heated with a smoky flame until oils come over freely and carry no trace of water with them, but the distillation should not be unnecessarily continued.

The distillate is received in a properly graduated 25 c. c. cylinder, allowed some time to separate completely, and the volume of water read. The number of cubic centimeters of water multiplied by 2 equals the percentage of water. Ordinarily the process offers no difficulties. A dip extremely high in rosin may bump and froth over, no matter how carefully heated. In such a case a larger flask is used, and the dip is diluted with about an equal volume of water-free mineral or coal-tar oil. In case separation of the distillate is imperfect a small measured amount of strong NaCl solution is added from a pipette, and the cylinder is nearly filled with benzol, shaken, and left at rest for some time. The volume of NaCl solution added is of course to be deducted when the reading is taken.

DETERMINATION OF SODA AND PYRIDIN BASES.

The method, which is a novel combination and adaptation of well-known principles and processes, depends upon the fact that pyridin bases are alkaline toward methyl orange, but not toward phenolphthalein. A known weight of dip is shaken in a separatory funnel with ether and water to which a known amount of sulphuric acid has been added. Rosin soap is thus decomposed, and all bases contained in the dip will pass as sulphates into the lower acid aqueous layer which soon separates. The latter is quantitatively removed, and, ignoring acid salts for the sake of simplicity, will contain the substances—

	(a)	(b)	(c)
Stage I.	Na_2SO_4.	H_2SO_4.	$(C_5H_5N)_2H_2SO_4$.

If methyl orange is now added and the solution titrated to neutrality with standard caustic soda the result will be—

	(a)	(b)	(c)
Stage II.	Na_2SO_4.	Na_2SO_4.	$(C_5H_5N)_2H_2SO_4$.

If next phenolphthalein is added and titration with standard caustic soda continued until the solution is neutral to that indicator, the final condition of the solution will be—

	(a)	(b)	(c)	
Stage III.	Na_2SO_4.	Na_2SO_4.	Na_2SO_4.	C_5H_5N.

Obviously the amount of caustic soda required to change the solution from Stage II to Stage III will be a measure of the amount of pyridin present, while if the amount of caustic soda added in the whole titration is subtracted from the equivalent in soda of the sulphuric acid originally introduced the remainder will equal the amount of soda in the dip. Briefly, the amount of soda equivalent to H_2SO_4 (c) measures pyridin; soda equivalent to H_2SO_4 [(a+b+c)—

(b+c)] is the soda of the dip. The process is executed in the following manner:

Ten grams of dip is weighed into a 200 c. c. short-stemmed separating funnel, 50 c. c. ether added, exactly 30 c. c. of N/2 H_2SO_4 run in from a burette and the funnel shaken. The lower aqueous layer, which now contains the bases, is drawn off completely, together with any insoluble carbonaceous matter which may appear at the junction of the two layers. No harm is done if a small amount of the ethereal layer accompanies the insoluble matter in the separation. The ethereal solution remaining in the funnel is next washed four times with water, using about 20 c. c. each time. In the first of these washings the funnel should not be shaken, but the water should be drawn off at once, the object being to wash out the stem of the funnel and so avoid loss of a little acid therein contained.

All the aqueous extracts are united and heated on the steam bath for expulsion of ether. The liquid is then passed through a wet filter into a 300 c. c. flask, the filter washed with hot water, the flask cooled, filled to the mark, and the contents exactly divided between two uniform titrating flasks of about 300 c. c. capacity. To one of these portions add methyl orange, then N/2 NaOH till the red tint just disappears, as nearly as can be determined by comparison with the second portion. Then add one-tenth or two-tenths of a cubic centimeter more of N/2 NaOH to make sure that neutrality has been reached, though much excess must be avoided, else the separation of higher pyridin bases will render the solution turbid.

This first titration is not quantitative, but merely to afford a standard of comparison, by the aid of which the second portion is quantitatively titrated to exact neutrality, after the addition of an equal amount of methyl orange. The number of cubic centimeters of N/2 NaOH used is noted, phenolphthalein added, and the titration continued to the end point of that indicator. To obtain the per cent of Na_2O in the dip, subtract the total number of cubic centimeters of N/2 NaOH used in the whole titration of the second portion from 15, and multiply the remainder by 0.31. To obtain the per cent of volatile bases reckoned as pyridin, multiply the number of cubic centimeters of N/2 NaOH used between the end points of methyl orange and phenolphthalein by 0.79. The only difficulty in the method is the determination of the point of neutrality toward methyl orange, but a proper use of the standard of comparison will satisfactorily overcome this.[a]

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[a] Recent work has indicated that the coloring matters which tend to interfere with the accurate observation of the end point with methyl orange may be almost entirely removed from the solution by the use of animal charcoal. Powdered animal charcoal is digested on the steam bath with dilute hydrochloric acid in sufficient quantity to decompose and dissolve all carbonates and

Results obtained for pyridin run between 0.05 and 0.1 per cent higher than by Allen's method.

DETERMINATION OF PHENOLS.

The regulations of the Department of Agriculture[a] include under the designations "phenols," "cresols," and "cresylic acid" those phenols whose boiling points range between 185° C. and 250° C. Benzophenol, or pure carbolic acid, having a boiling point of 182° C., is accordingly excluded, the reason for such distinction being that it is considerably more toxic in its effect upon animals than the phenols of higher boiling points. As a matter of fact the comparatively high market value of pure carbolic acid as a separate product renders unlikely the presence of more than traces of it in such compounds. It is well known that the so-called crude carbolic acid of commerce consists almost entirely of higher phenols.

There are but few methods for determining phenols which have received at all extended application. Of these the only direct acidimetric method, that of Bader,[b] is applicable to benzophenol alone, and hence is of no value in the present case. A direct gravimetric determination, in addition to its inherent sources of error, demands a complete separation of hydrocarbons from the phenols. So also does any volumetric method based upon the reaction between phenols and bromin or iodin. This separation of hydrocarbons from phenols, as noted under the description of the scientific method of analysis, is tedious and uncertain, and is to be avoided if in any way possible.

There will appear, then, to be two methods practically applicable in the present case—the method of Schryver,[c] by which the phenols are acted upon in benzol solution by sodamid and the evolved ammonia titrated, and the German method of measuring the increase in

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phosphates present, then washed with hot water until the wash water is free from chlorids, and finally dried and powdered.

In the course of an analysis, after the flask containing the acid extract from the dip has been heated upon the steam bath until ether has been completely expelled, 1 to 1.5 grams of the purified animal charcoal is added, and the flask, frequently shaken, is left upon the steam bath for 30 to 60 minutes. The contents are then filtered, washed, and titrated as usual. After proper treatment with animal charcoal in this manner the solution will be a pale green in color, possessing none of the muddy yellow tint which tends to obscure the end point with methyl orange.

Experiments have thus far failed to show that any inaccuracy is introduced into the method by the use of animal charcoal in the manner described.

[a] Bureau of Animal Industry Order 143, p. 18.

[b] Zeitschrift für Analytische Chemie, Jahrg. 31, p. 58–60. Wiesbaden, 1892.

[c] Journal of the Society of Chemical Industry, vol. 18, No. 6, p. 553–556. London, June 30, 1899.

volume of a caustic soda solution when the phenols are absorbed by it. In either case the phenols may be separated from interfering substances by steam distillation of the acidified dip. Schryver's method is essentially a direct determination of the amount of phenol hydroxyl present, and the actual weight must be obtained through a knowledge of the mean molecular weight derived from other considerations. The German method, on the other hand, is a measure of the volume of the phenols when in solution under certain conditions, and the corresponding weight can be obtained only by the employment of an empirical factor or coefficient found to hold true for that particular kind of phenol under those particular conditions. Since in both methods a certain factor must be somewhat arbitrarily adopted by which the numbers directly obtained are to be multiplied in order to obtain the weight of phenols present, and since the possible error thereby involved appears of about the same magnitude in both, that one will naturally be chosen which is easiest of execution, in which respect Schryver's method is at a decided disadvantage.

The methods of procedure which considerable experimental work has shown to be satisfactory is as follows:

Fifty grams of dip is weighed into a 500 c. c. round-bottomed flask, 20 c. c. of 1:3 H_2SO_4 is added, and the phenols are distilled off with steam. The flask will require no heating if a rapid current of steam is passed into it, but may with advantage be packed in cotton or felt. Obviously the apparatus must be so set up and the distillation so conducted that particles of rosin may not be mechanically carried over by the current of steam. Toward the end of the distillation any naphthalene in the condenser is melted out by shutting off the water for a few minutes, or if separated earlier in sufficient quantity to threaten stoppage of the condenser tube, distillation is interrupted while hot water is run through the condenser. The distillate is received in a liter flask approximately marked for each 100 c. c. capacity and joined to the condenser by a cork which is pierced by a small glass tube connected to a small U tube containing a little dilute caustic soda. The latter acts as a trap to prevent any loss of the distilled phenols. Distillation is continued until 1 or 2 c. c. collected in a test tube gives no reaction with any appropriate reagent for phenols, such as ferric chlorid. A volume of 800 c. c. is ample in nearly all cases.

A supply of benzol should be prepared by shaking a good grade of benzol with dilute sulphuric acid, then with dilute caustic soda two or three times, and then passing through a dry filter. A small wash bottle containing some of this benzol will be found very useful for rinsing the necks of separatory funnels, etc. Of this purified benzol 150 c. c. is measured out conveniently at hand, the contents of the U tube and 5 c. c. of 1:1 H_2SO_4 are added to the distillate, and the latter is shaken up and poured into a separatory funnel of 1,500 c. c. capacity, the flask being rinsed out with successive portions of the 150 c. c. benzol. When all is in the funnel 25 grams of clean sodium chlorid is added for each 100 c. c. of distillate, and the funnel is well shaken for five minutes and left at rest one-half hour. The aqueous layer is then run off slowly and completely, the funnel being allowed to stand until there is no further separation. The benzol solution of phenols and hydrocarbons is transferred to a 500 c. c. Erlenmeyer flask, while the aqueous portion is poured back into the separating funnel and extracted twice more in the same way, 100 c. c. of benzol being used each time. The funnel should always be gently handled after the aqueous portion has been drawn off, to prevent any impurities from the sodium chlorid which have deposited upon its sides from becoming mixed with the benzol solution. The three benzol extracts are united in the Erlenmeyer flask, 15 c. c. of pure caustic soda solution, 1:2, is added, and the contents of the flask are subjected to a rotatory motion for some time in order that the phenols may be taken up by the caustic soda as completely as possible.

After the addition of a few grains of sand the flask is immersed in a water bath, connected to a condenser, and all but 40 to 50 c. c. of the benzol distilled off. With the aid of a wash bottle containing water and provided with a fine jet, only a small portion of water being used at a time, the contents of the flask are next carefully washed into a 150 c. c. separatory funnel. With proper manipulation the flask should be completely washed when the volume of aqueous portion in the separatory funnel amounts to not more than 50 c. c. Ten cubic centimeters of strong sulphuric acid (100 c. c. pure concentrated H_2SO_4 to 120 c. c. water) is next slowly introduced with gentle rotation of the funnel, the addition of acid being interrupted and the funnel cooled whenever it becomes unpleasantly warm to the hand. Two or three drops of methyl orange are now added; and if on mixing the contents of the funnel the lower layer does not acquire a pink color, the addition of acid is continued until acidity is assured. Sufficient benzol is then added to make the two layers in the funnel approximately equal in volume, the funnel is thoroughly shaken and, with loosened stopper, left at rest for two hours. After that time the aqueous layer is slowly and completely run out, the analyst making sure that on longer standing no more will drain down from the sides of the funnel. The benzol solution of phenols is then ready to be transferred to the measuring tube.

The measuring tube consists of a glass-stoppered pear-shaped bulb of about 100 c. c. capacity, joined at its tapering end to a tube about 1 foot long and of a capacity of 25 to 30 c. c. This tube is accurately graduated to contain 25 c. c. at 20° C. in divisions of one-tenth c. c. (See fig. 1.)

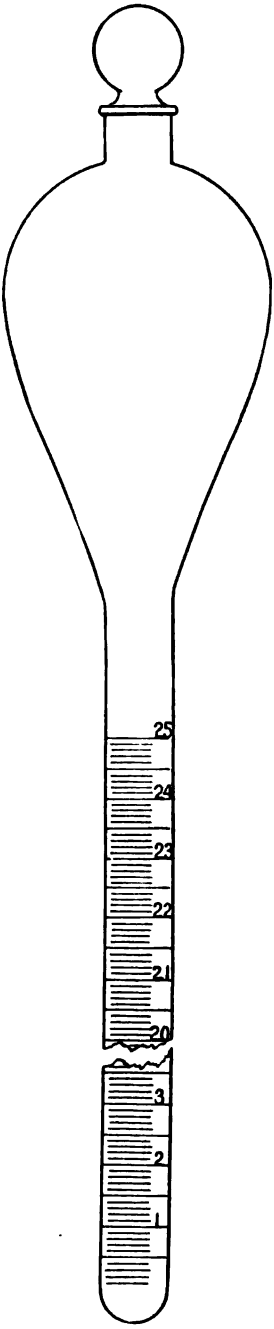

FIG. 1.—Tube for measuring phenols.

The apparatus is cleaned thoroughly with soap powder and hot water, and dried, best spontaneously, though alcohol and ether may be used if pure. Perfect cleanliness is essential to insure a properly shaped meniscus. Between 15 and 16 c. c. of caustic soda solution, 1:3, is brought into the tube with a pipette. The caustic soda should not be allowed to come in contact with the interior of the bulb or the upper part of the tube. After a few moments about 1 c. c. of benzol is added, and after waiting a little the height to the top of the now almost flat meniscus is noted. The benzol solution of phenols is next transferred from the separatory funnel to the tube, care being used to avoid mixing with the soda; the separatory funnel is washed out with a little benzol, which is also transferred to the tube, and the height of the meniscus is again noted. The latter may often be obtained more accurately at this point. The tube is then stoppered, vigorously shaken for three minutes, and set aside for at least three hours. An occasional rapid rotation of the tube between the palms of the hands will insure a complete separation of the layers. Each cubic centimeter increase in volume of the caustic soda solution may be taken to represent one gram of phenols. All readings of the tube should be taken at the top of the meniscus and at a temperature as near 20° C. as practicable.

This method of treating the distilled phenols is essentially that of Spalteholz,[a] though the details of its execution were not imparted in the original communication and had to be worked out independently. A discussion of the reasons for the different steps of the foregoing process will be entered into in a later section which deals with the experimental work done (see page 27).

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[a] Chemiker-Zeitung, Jahrg. 22, no. 8, pp. 58–59, Cöthen. Jan. 26, 1898.

From certain experiments it seems possible that a continuous extraction apparatus may be successfully employed to extract phenols from the aqueous distillate of the dip, using benzol as the solvent, and introducing caustic soda solution into the distillation flask of the apparatus at the beginning of the operation to retain the extracted phenols. When the extraction is completed the small flask of the apparatus will contain all the phenols, dissolved in a limited amount of caustic soda solution and overlaid by about 50 c. c. of benzol. The contents of the flask may then be brought readily and completely into a separatory funnel and acidified in the usual manner. Certain exigencies of the work in this laboratory have rendered somewhat inconvenient at the present time a practical test of this method of procedure in the routine examination of dips submitted for analysis.

DETERMINATION OF ROSIN ACIDS.

Resins in general have been shown to contain at least three different classes of bodies:[a] (1) resin acids or anhydrids, (2) esters of these or similar acids, (3) indifferent neutral bodies, perhaps hydrocarbons. Common rosin, or colophony, contains, according to Allen,[b] between 83.4 and 93.8 per cent of free rosin acids or anhydrids. The remaining 6 to 17 per cent consists of neutral bodies, soluble in ether and not extracted from ethereal solution by aqueous caustic soda, and accordingly there would seem to be no practicable means of distinguishing and separating them from the coal-tar hydrocarbons of the dip. Apparently, then, the analyst must be content with a determination of the amount of rosin acids present, which will represent about nine-tenths of the amount of rosin actually used in manufacturing the dip. Either a gravimetric or a volumetric method may be employed.

Owing to the degree of uncertainty attached to the exact combining equivalent of the rosin acids in each particular dip, the gravimetric method has an indubitable advantage in point of accuracy when properly carried out. But as a matter of fact the combining equivalents of a considerable number of rosin acids obtained from different dips in the gravimetric way in the course of analysis have been found to vary very little, not enough in any case to cause a possible error of half a per cent in the analysis of a dip of ordinary constitution. Moreover, in view of the difficulty of completely separating hydrocarbons from rosin acids, as is necessary in the gravimetric method, it is probable that the ordinary analyst without considerable practice in this particular operation will obtain quite as accurate results by the volumetric method as by the gravimetric. Accordingly the volumetric method would seem to recommend itself for use in ordinary routine work on account of its greater rapidity, simplicity, and probable equal accuracy under ordinary conditions, while the gravimetric method may be reserved for dips extremely high in rosin or for a confirmatory method in special cases.

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[a] Allen, A. H., Commercial Organic Analysis, 3d ed. rev., Vol. II, Pt. III, p. 141. 1907.

[b] Id., p. 160.

For the determination of rosin acids by either method it is most advantageous to make use of the residue left in the distillation flask after the determination of phenols. From this residue all phenols and a large part of the hydrocarbons have been removed, hence the necessary extraction by ether is expedited. After cooling, the aqueous portion of the contents of the flask is poured into a separatory funnel, with as little rosin as possible, and extracted with ether. The aqueous portion is run off and discarded, the residue in the flask is completely dissolved and brought into the funnel with ether, 40 to 50 c. c. of water is added, and the funnel well shaken. The presence of insoluble carbonaceous matter will usually cause a persistent emulsion at the junction of the two layers, which may, in fact, entirely fill the lower part of the funnel.

This is wholly run off into a 300 c. c. Erlenmeyer flask and the ethereal solution well shaken again with successive portions of water, the water being run off each time to the clear ethereal solution, until the carbonaceous matter is wholly removed and separation takes place in the funnel quickly and cleanly. These wash waters are all received in the flask containing the first separated emulsion, and this is heated upon the steam bath until ether is expelled. The contents are then brought more or less completely upon a wet filter and washed with hot water. At this point the methods diverge.

Gravimetric method.—In case the gravimetric method is to be employed, after a brief washing of the insoluble carbonaceous residue with hot water both flask and filter are well drained. Both are then washed, first with a little absolute alcohol to remove water, then thoroughly with ether until all rosin is dissolved and the filtrate comes through colorless.

The united ethereal solution of hydrocarbons and rosin is now thoroughly shaken with about 40 c. c. of 15 per cent caustic soda. On separation there will be three layers. The lowest one usually contains very little rosin soap, and consequently holds but a small amount of hydrocarbons. It is best run off and washed separately with ether. One washing will usually free it completely from hydrocarbons.

After the first layer has been thus removed, about 50 c. c. of water is added to the funnel and the latter is well shaken. The lower layer of rosin soap is run off and followed by 5 to 10 c. c. of water without shaking, the funnel being given only a gentle rotatory motion. The remaining ether solution of hydrocarbons is washed twice with 20 to 25 c. c. of about 4 per cent caustic soda solution, each washing being followed by a little water as before described. These two washings with dilute caustic soda are kept apart and not added to the main solution of rosin soap.

The main solution of rosin soap is now washed in a separatory funnel with successive portions of ether, followed through each time by 5 c. c. of water, as at first, until the ether is left nearly colorless. The ether extracts are shaken through in their order with the two washings of dilute caustic soda already used, and a third if needed, each being followed with a few cubic centimeters of water.

All the aqueous extracts are united in a porcelain dish or casserole, which should be not more than half filled by them, and are evaporated on the steam bath until ether is dissipated and the volume reduced to a convenient amount. The contents of the dish are then transferred to a separatory funnel with the aid of a spatula and hot water; strong sulphuric acid is added to decompose all rosin soap, and after complete cooling the rosin acids are extracted by ether and washed with water till free from sulphuric acid. The ethereal solution is brought into a weighed Erlenmeyer flask with a few grains of sand, the ether is distilled off, and the flask is heated in an oven at 110° C. until the absence of frothing on rotation shows elimination of water; it is then cooled and weighed.

Volumetric method.—As already noted, the volumetric method proceeds identically with the gravimetric to the point where carbonaceous matter is brought upon the filter and washed with hot water. The washing in this case must be continued until the wash water comes through entirely free from acid reaction. The main ethereal solution has meanwhile been brought into a flask and the ether distilled off. The filter funnel is set in the neck of this flask, and the carbonaceous matter is washed with hot alcohol previously rendered neutral to phenolphthalein, until freed from rosin. The alcoholic solution of rosin is brought into a graduated flask, and an aliquot part, usually one-fourth, taken for titration with half-normal caustic soda. The titration is conveniently carried out in a 200 c. c. Erlenmeyer flask in a volume of 100 to 125 c. c., the portion taken being diluted with neutralized alcohol to that amount.

Owing to the very dark color of the liquid an external indicator is necessary. For this purpose alkali blue is best adapted. A few drops of a strong alcoholic stock solution are added to 25 or 30 c. c. of alcohol, which is then carefully neutralized with tenth-normal caustic soda. Enough alkali blue should be added to produce a deep color, almost a cherry, when neutralized, with no trace of violet. This dilute indicator should be freshly prepared. A supply of small test tubes 8 to 10 millimeters in diameter and 60 to 80 millimeters long should be at hand, cleaned and dried. When a test of the progress of the titration is to be made about ½ c. c. of prepared indicator is poured into one of these test tubes, and to this is added a drop of the liquid under titration. If a violet color appears, the solution still contains free rosin acid, and more N/2 NaOH must be added and the solution again tested with a fresh tube of indicator. If the indicator does not show a violet color upon the addition of one drop of the liquid under titration, addition of the latter is continued drop by drop until an amount has been added approximately equal in volume to the amount of indicator originally in the tube, i. e., ½ c. c. The continued absence of a violet color after the addition of this amount indicates that the solution is either neutral or alkaline. The end of the titration then is reached when a greenish or violet tint just fails to appear. A fresh tube of indicator must be used for each test. It is best to proceed by running in 12 to 15 c. c. of half-normal caustic soda at once, testing and continuing addition if necessary, a cubic centimeter at a time, until the indicator shows alkalinity, then running back with half-normal hydrochloric acid, using perhaps 0.4 c. c. at a time till acidity is shown, and now working carefully with half-normal caustic soda to exact neutrality. One cubic centimeter of half-normal caustic soda is considered to be equivalent to 0.162 gram of rosin acids.

Phenolphthalein may also be used as an indicator in a similar way, by preparing an alcoholic solution of quite a deep rose tint. The end point of the titration will then be reached when the indicator, used in the same way as alkali blue, is no longer bleached by the addition of the liquid under titration. The color change is not so marked as in the case of alkali blue, and consequently the end point is not so sharp, though almost equally good results may be obtained with a little care and practice.

All alcoholic solutions should be kept from contact with air as far as possible to prevent absorption of carbon dioxid.

DETERMINATION OF OCCASIONAL INGREDIENTS.

Light oils.—The presence of light oils will usually be indicated by the relative proportions of oil and water which come over in the early stages of the process of distilling the dip for the determination of water. The odor of the distillate should be noted at this point, to identify if possible the nature of the light oils present. If more information is desired, about 150 grams of dip is thoroughly shaken with 20 to 25 c. c. of 1:3 sulphuric acid, allowed some hours to separate, and a weight of oils, etc., equivalent to 100 grams of dip—i. e., a weight in grams equal to the sum of the percentages of hydrocarbons, phenols, and rosin—is distilled from an Engel flask fitted with a thermometer until the temperature reaches 180° C. The distillate is measured and further examined in any way desired.

Naphthalene.—Too large a proportion of naphthalene or other solid hydrocarbons is undesirable on account of the liability of these bodies to separate from the dip in freezing weather and remain for a long time as an undissolved sediment. For an approximate determination of the amount of solid hydrocarbons present 50 grams of dip is acidified with a little concentrated hydrochloric acid, 100 c. c. alcohol added, and the containing vessel immersed in a freezing mixture for two hours, with occasional stirring. The separated hydrocarbons are then filtered off on a Buchner funnel or plate, washed somewhat with chilled alcohol, well drained, and pressed out in a letterpress between several thicknesses of filter paper. The mass may then be weighed and subjected to any further examination desired. A more practical test is to subject a portion of the dip itself to a temperature of 0° C. for about three hours, with occasional shaking or stirring. It should remain perfectly clear and liquid and show no separation of solid matter.

Foreign oils and creosotes.—By the regulations of the Secretary of Agriculture[a] the degree of dilution which may be accorded to a coal-tar creosote dip is explicitly made to depend upon the percentages of coal-tar oils and cresylic acid contained in the dip. Accordingly in the standardization of dips for official use, within the scope of the regulations, petroleum oil, rosin oil, or creosotes of other origin than coal-tar must be regarded as extraneous substances. Investigations are now in progress to find satisfactory methods for detecting and estimating these substances when present in dips. At the present time, however, this line of work has not reached a point of development which warrants the publication of any results.

CRESYLIC ACID DIPS.

Cresylic acid or cresol dips in composition approximate more or less closely the "liquor cresolis compositus" of the United States Pharmacopœia, eighth revision, 1905, being made from a potash-linseed oil soap and cresylic acid comparatively free from hydrocarbons. A properly prepared dip of this character should upon dilution in 100 parts of distilled water yield a practically water-clear solution, showing absence of any notable amount of hydrocarbons or unsaponified oil. On dilution, however, with hard water there will naturally be some turbidity, caused by the precipitation of soap. A portion of the dip when treated with successive small portions of water should show itself miscible in all proportions. At no stage should there be any notable turbidity or separation of heavy oily globules of cresylic acid due to absence of sufficient soap.

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[a] Bureau of Animal Industry Order 143, p. 18.

METHODS OF ANALYSIS ADOPTED BY THE BUREAU.

The methods of analysis adopted are essentially the same as for coal-tar creosote dips, modified in details to suit the somewhat different composition of the substances.

DETERMINATION OF WATER.

The distillate must always be received in a stoppered cylinder and treated with benzol and sodium chlorid solution as described. The results will be about 0.5 per cent too low. The addition of toluene or a similar hydrocarbon to the dip before distillation might possibly improve the results.

DETERMINATION OF POTASH (OR SODA) AND PYRIDIN.

A preliminary test is here necessary to determine whether potash or soda is the alkali present. The test may be conveniently made by shaking about 10 grams of dip with ether and a little dilute hydrochloric acid, drawing off the aqueous layer, and applying the flame test with a platinum wire, supplementing this with any other confirmatory test necessary or desirable. If potash is found to be the alkali present the factor 0.471 must be used in place of the factor 0.31 employed in the case of soda.

DETERMINATION OF PHENOLS.

Since the percentage of phenols will here be much higher than in coal-tar creosote dips, a smaller amount of dip must be taken for analysis, usually 15 to 20 grams. The amount should be as large as possible, in order that the greatest quantity of phenols within the capacity of the tube may be brought to measurement. A new opportunity for error is here afforded. Linseed oil possesses a low Reichert-Meissl number, 00 to 1.43.[a] This means that a small amount of volatile fatty acid will accompany the phenols through the stages of the process and tend to cause too high results. To determine the possible amount of this error 25 grams of linseed oil was saponified, then acidified, and distilled with steam until 800 c. c. had been collected. The distillate was treated by the regular method and an increase in volume between 0.02 and 0.07 c. c. observed. In view of the fact that this quantity of soap is four or five times as much as would be present in an ordinary analysis, the error which is likely to arise from this source would appear negligible.

DETERMINATION OF ROSIN OR FATTY ACIDS.

The odor of the dip itself, and more especially the character of the residue left in the flask after the distillation of phenols, will inform the analyst whether rosin or fatty acids are to be determined. Rosin will collect in a solid, hard button at the bottom, while fatty acids will form a liquid oily layer floating upon the surface of the aqueous contents. In either case the whole is extracted with ether, washed with water, and, after evaporation of ether, dissolved in neutralized alcohol and titrated with half-normal caustic soda. One cubic centimeter of half-normal soda will represent 0.138 gram fatty acid anhydrids[a] and 0.015344 gram glycerin. Cresol dips containing rosin soap are not at present permitted in official dipping.

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[a] Hopkins's Oil Chemists' Handbook, page 38.

Such a detailed analysis of a cresol dip would appear, however, seldom necessary. Phenols must of course be determined as accurately as possible. An examination of the odor and appearance of the residue left in the flask after distillation of phenols will indicate the character of the soap employed. If, then, the behavior of the dip upon dilution is satisfactory (page 21) and indicates the presence of sufficient soap, the only remaining question is whether there may be an unnecessary and possibly harmful amount of alkali present. In the presence of the large amount of cresylic acid contained in these dips there can be, strictly speaking, no "free alkali." The ideal cresol dip will, however, unquestionably contain no alkali above that necessary to obtain complete saponification of the linseed oil. An excess of alkali can be of no possible benefit and might conceivably be undesirable for several reasons. A useful test for the presence of such an excess of alkali is that of Kelhofer.[b]

Ten grams of dip is thoroughly shaken in a small separatory funnel with 50 c. c. of a saturated solution of NaCl. After complete separation has taken place the lower aqueous layer is removed, diluted with an equal volume of water, and a few drops of phenolphthalein added. If the dip has been made from a perfectly neutral linseed-oil soap, there will appear at most but a slight reddening of the solution, which vanishes upon the addition of a drop of half-normal acid. If more acid is required to remove the pink color, the presence of an excess of alkali is indicated. The test can not be made quantitative, for experiments have shown that only a part of the excess of alkali actually present is accounted for in this way, the remainder probably being thrown up in the form of alkali cresylate into the upper layer with the soap. It would seem, then, reasonable to demand that no dip treated as described should require more than a very few tenths of a cubic centimeter of half-normal acid to remove the pink color imparted by phenolphthalein to the sodium chlorid extract.

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[a] Lewkowitsch, J., Chemical Technology and Analysis of Oils, Fats, and Waxes, 3d ed., Vol. I, p. 334. 1904.

[b] Schweizerische Wochenschrift für Chemie und Pharmazie, Jahrg. 46, No. 2, pp. 19-20. Zurich, Jan. 11, 1908.

Duyk[a] proposes a method for the determination of soap in cresol dips, according to which the soap is separated by shaking the dip with a strong sugar solution. The latter dissolves all the soap, which may be recovered by salting out with NaCl, and purified, if desired, by solution in alcohol. The method has not been tried in this laboratory.

ANALYSIS OF COAL-TAR OILS AND COMMERCIAL CRESYLIC ACID.

Obviously it is impossible for a manufacturer to produce a dip of constant composition closely adhering to the standard he has set for himself in his original sample submitted to the Department of Agriculture for examination unless he knows exactly what goes into each lot of dip his factory turns out. The composition of coal-tar oils is subject to considerable variation; consequently it is absolutely necessary for any manufacturer who wishes to secure and retain permission for the use of his dip in official dipping to have at his disposal some means of accurately analyzing each lot of coal-tar oils he receives. He may then blend his oils, or his oils and cresylic acid, in such proportions as always to preserve uniform the composition of his dip.

The coal-tar oils to be used for dips must be examined for water, pyridin bases, and phenols.

Water will be determined exactly as in dips (page 10).

Pyridin bases will be determined exactly as in dips (page 11), but if the oils are old and highly colored it may prove advantageous to use 5 grams instead of 10.

The hope was entertained that phenols in coal-tar oils and cresylic acid might be readily and accurately estimated by dissolving a weighed amount in benzol, shaking with acidified aqueous sodium sulphate to remove water, and then shaking the separated benzol solution in the measuring tube with caustic soda; in short, by repeating exactly the last two steps of the method employed for phenols in dips. In fact, the latter was adopted for dips with considerable added satisfaction because it seemed to promise an easy solution of one of the most troublesome problems of dip making by affording such a simple means for valuing coal-tar oils, requiring no special technical training for its execution, and yet being a method strictly parallel in all respects to the method employed in analyzing the completed dip.

This hope was not realized, for it was found that some samples at any rate of creosote oils and of cresylic acid contain small amounts of acid bodies of some description, possibly phenoloids, possibly of a resinous nature, which are taken up by caustic soda, increasing its volume, but which are not volatile with steam. There seems to be no way of determining these bodies in the dip, provided they are phenoloids; hence it seems necessary to define cresylic acid within the scope of the regulations as "phenols derived from coal tar, none of which boils below 185° C. nor above 250° C.," and which are completely volatile with steam at 100° C. The only resource, accordingly, is to handle the oils and cresylic acid in exactly the same way as the dips themselves are handled (page 13), by distillation of an appropriate weight of the acidified oil in a current of steam, with the subsequent extractions and measurement as described.

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[a] Annales de Chimie Analytique, t. 12, No. 9, pp. 345–346. Paris, Sept. 15, 1907.

As might be expected, cresylic acid appears to contain a smaller per cent of these acid bodies not volatile with steam than does creosote oil. Very probably the amount is subject to considerable variation in different samples. Results on certain samples will be given in the section on experimental work (page 33).

CALCULATION OF PROPER DILUTION OF DIPS.

COAL-TAR CREOSOTE DIPS.

The regulations of the Secretary of Agriculture[a] state that a coal-tar creosote dip "should contain when diluted ready for use not less than 1 per cent by weight of coal-tar oils and cresylic acid. In no case should the diluted dip contain more than four-tenths of 1 per cent nor less than one-tenth of 1 per cent of cresylic acid; but when the proportion of cresylic acid falls below two-tenths of 1 per cent the coal-tar oils should be increased sufficiently to bring the total of the tar oils and the cresylic acid in the diluted dip up to 1.2 per cent by weight."

In calculating from the composition of a dip its proper dilution under this regulation three points must be borne in mind. First, the regulations demand that hydrocarbons and phenols must be present in certain minimum percentages by weight, whereas in practice a dip is always diluted by volume. Second, the regulations set two independent minimum pairs of values below which the percentages of phenols and of hydrocarbons and phenols may not fall, though they may rise above these set values within certain limits, thus allowing a considerable range in the possible composition of a dip. Third, the calculated dilution must be the greatest possible dilution which the dip under consideration can obtain under the regulations.

Three steps will then be involved in the calculation of the dilution of a coal-tar creosote dip. (1) The selection of the pair of minimum percentages of phenols and of hydrocarbons and phenols most advantageous for that particular dip; (2) the calculation of the maximum dilution by weight which a dip of that composition can be granted under the section of the regulation most advantageous to it; (3) by employment of the specific gravity of the dip as a factor to pass from the obtained maximum dilution by weight to the maximum dilution by volume.

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[a] Bureau of Animal Industry Order 143, page 18.

These data having been thus fully set forth, it hardly seems necessary to enter into the actual solution of the problem, since the matter is purely one of mathematics. It will be sufficient to state that a mathematical analysis of the above regulation will lead to the following four cases and the four corresponding rules for obtaining the maximum dilution in each case:

Case I.—When the percentage of phenols is less than one-twelfth of the sum of the percentages of hydrocarbons and phenols.

Rule: Multiply the percentage of phenols by 10, subtract 1 from the product, and multiply the remainder by the specific gravity of the dip.

The diluted dip will then contain 0.1 per cent phenols and over 1.2 per cent hydrocarbons and phenols.

Case II.—When the percentage of phenols is between one-twelfth and one-sixth of the sum of the percentages of hydrocarbons and phenols.

Rule: Divide the sum of the percentages of hydrocarbons and phenols by 1.2, subtract 1 from the quotient, and multiply the remainder by the specific gravity of the dip.

The diluted dip will then contain 1.2 per cent of hydrocarbons and phenols and between 0.1 and 0.2 per cent of phenols.

Case III.—When the percentage of phenols is between one-sixth and one-fifth of the sum of the percentages of hydrocarbons and phenols.

Rule: Multiply the percentage of phenols by 5, subtract 1 from the product, and multiply the remainder by the specific gravity of the dip.

The diluted dip will then contain 0.2 per cent phenols and between 1 and 1.2 per cent hydrocarbons and phenols.

Case IV.—When the percentage of phenols is between one-fifth and two-fifths of the sum of the percentages of hydrocarbons and phenols.

Rule: Subtract 1 from the sum of the percentages of hydrocarbons and phenols, and multiply the remainder by the specific gravity of the dip.

The diluted dip will then contain 1 per cent hydrocarbons and phenols and between 0.2 per cent and 0.4 per cent of phenols.

In each case the result obtained by the rule is the number of parts by volume which may be added to one part by volume of the dip; in practice, the greatest number of gallons of water which may be added to one gallon of dip.

It may be stated that if the percentage of phenols is greater than two-fifths of the sum of the percentages of hydrocarbons and phenols, the use of the dip can not be permitted under the regulations, for when diluted until it contains 1 per cent of hydrocarbons plus phenols, the minimum allowed, it will necessarily contain above 0.4 per cent of phenols, which amount is set as the maximum limit.

CRESYLIC-ACID DIPS.

The aforementioned regulations state in regard to the cresol dip that "when diluted ready for use this dip should contain one-half of 1 per cent of cresylic acid." From this may be derived the rule: Multiply the percentage of phenols by 2, subtract 1 from the product, and multiply the remainder by the specific gravity of the dip.

EXPERIMENTAL WORK WITH METHODS OF ANALYSIS.

Much experimental work was done in developing and testing the previously described methods of analysis. A brief outline of some of this experimental work, with a more detailed discussion of certain results, may be of interest.

DETERMINATION OF PHENOLS.

Particular difficulty was experienced with phenols. It early became clear that the most desirable method of finally estimating their amount would be by measuring the increase of volume shown by a solution of caustic soda when the phenols in question were absorbed by it. The general reasons for this conclusion have already been discussed. Attention will now be paid to some special points involved.

I. When weighed amounts of pure phenols are shaken in the measuring tube as described, and the coefficient $\frac{\text{weight phenols}}{\text{volume increase NaOH}}$ determined, it was found that—

(*a*) This coefficient is constant for a given phenol irrespective of the amount measured—within the limits of the tube—and of the presence or absence of other coal-tar hydrocarbons in addition to benzol. To illustrate, weighed amounts of a fairly pure cresylic acid were dissolved in benzol and shaken in the measuring tube with caustic soda, with the following results:

Weight of cresol.	Increase in volume of NaOH.	Coefficient: $\left(\frac{\text{weight phenols}}{\text{volume increase NaOH.}}\right)$
Grams.	*Cubic centimeters.*	
9.1385	8.66	1.055
9.2825	8.62	1.078
9.5160	8.82	1.079
2.3893	2.22	1.076
2.3228	2.19	1.060

Although approximately four times as much cresol was employed in the first three trials as in the last two, the derived coefficient is practically identical.

(*b*) This coefficient is not the same for all phenols, but varies in the same direction as the specific gravity of different phenols, though in greater ratio, accordingly varying inversely as the molecular weights of the different phenols and in approximately equal inverse ratio. For the mixtures of phenols ordinarily occurring in commercial cresylic acid and in the grades of coal-tar creosote oils commonly used for making dips, the average coefficient proved to be unity as nearly as could be determined.

II. When weighed amounts of pure phenols were shaken in a separatory funnel with water, soda, sulphuric acid, and benzol in the proportions described in the analytical method, and the phenols then brought to measurement, the coefficients in all cases were found to run parallel to those obtained in Experiment I, but to be very slightly lower; that is, water is carried by the phenols into benzol solution in amount rather more than enough to balance the amount of phenols retained by the acid aqueous layer in the separatory funnel. No loss is therefore here involved.

III. The validity of the method of measurement having been thus established, the next problem was to concentrate without loss of phenols the large volume of distillate resulting from the distillation of the acidified dip with steam to a volume sufficiently small to be introduced into the measuring tube.

(*a*) The first attempt was concentration by evaporation of the liquid after rendering it strongly alkaline. Weighed amounts of phenols were dissolved in 800 c. c. of water and 25 c. c. of caustic soda 1:3, and evaporated to 40 to 50 c. c. on the steam bath, and the phenols were then separated and brought to measurement as described. It was found that this proceeding involved a loss averaging at least 5 per cent, the percentage increasing as the molecular weights of the phenols increased. This result could be expected, for the higher phenols, being of much less solubility in dilute caustic soda, and being more weakly acid and their salts consequently more easily hydrolyzed, would naturally suffer a greater percentage of loss than the lower, more acid phenols.

(*b*) An attempt was next made to extract phenols from the distillate with benzol, then concentrate the benzol solution by distillation to a residual quantity of about 60 c. c., which was lastly brought into the measuring tube with caustic soda. Weighed amounts of phenols were brought into a 1,500 c. c. separatory funnel with 800 c. c. of water, and shaken with benzol in the amount and manner described in the analytical method (page 15), both with and without the addition of NaCl. Without addition of NaCl each extraction with benzol removes at most but 75 per cent of the phenol present each time; with 12½ grams NaCl per 100 c. c. about 87 per cent is withdrawn, and with 25 grams per 100 c. c., between 92 and 94 per cent is taken up by the benzol in each extraction. Three extractions as described will therefore account for 99.95 per cent of the amount of phenols originally present. This was eminently satisfactory. But when the benzol extract was submitted to distillation, variable amounts of phenols were found in the distillate, the amount being almost negligible in the case of phenols of high boiling point, but considerable with the lower phenols, and especially notable in the case of benzophenol.

(*c*) Attempt was next made to hold back phenols while benzol was being distilled as described in (*b*), by the addition of a few grams of metallic sodium, the idea being to eliminate the effect of small amounts of water and at the same time to bring the phenols into a completely nonvolatile compound. This attempt was quickly abandoned, for the reaction between sodium and phenols proved very slow and incomplete, even on long standing or boiling with reflux condenser.

(*d*) It will be noted that high-boiling phenols suffer special loss by the method of (*a*) and low-boiling phenols by method (*b*), while the method of extraction of (*b*) is perfectly adequate. Therefore an attempt was made to combine the two methods by distilling off the benzol over strong caustic soda—15 c. c. of 1:2 NaOH—the idea being that the strong caustic soda would hold nearly all the phenols in combination, and afford on account of its concentration but slight opportunity for hydrolysis and formation of water vapor, while since those very phenols most subject to hydrolysis and loss from the caustic soda are those of high boiling point and but slight volatility with vapors of benzol, practically no appreciable amount of phenols would escape from the flask. This proved to be the case. Delicate qualitative tests show the presence of phenols in the distillate, but in amount far beyond the power of the measuring tube to detect.

The following table will illustrate some of the positive points brought out in Experiments I, II, and III. Purified cresol was employed, obtained in the laboratory from crude cresylic acid.

Results of experiments upon the method for determining phenols.

Method of treatment.	Weight taken.	Increase of NaOH.	Coefficient: $\left(\frac{\text{weight phenols}}{\text{volume increase NaOH.}}\right)$	Mean coefficient.
	Grams.	*Cubic centimeters.*		
Dissolved in benzol and shaken with NaOH in tube	6.855	6.69	1.023	1.019
	8.625	8.50	1.015	
In separatory funnel with benzol, NaOH, and H_2SO_4, then as in analysis	7.542	7.52	1.003	1.003
	7.773	7.75	1.003	
With 800 c. c. water, 200 g. NaCl, then treated as in analysis	8.433	8.30	1.016	1.004
	9.776	9.81	.997	
	9.344	9.40	.998	

It is evident, accordingly, that the method described will bring to measurement, with no loss, all the phenols present in the distillate from the dip.

TESTS WITH COAL-TAR CREOSOTE DIPS OF KNOWN COMPOSITION.

The next undertaking was to make up a coal-tar creosote dip of accurately known composition in order to test upon it the validity in practice of the methods of analysis developed.

Dip No. 1.—Rosin: A fair grade of ordinary commercial rosin was employed. Weight used, 220 grams.

Hydrocarbons: Coal-tar oils, supposed to be free from phenols, shaken four times with 10 to 25 per cent caustic soda, dried over calcium chlorid, and filtered. Weight taken, 550 grams.

Pure phenols: Obtained by the purification in the laboratory of crude cresylic acid. Weight taken, 120 grams.

Caustic soda and water: One part pure NaOH dissolved in two parts water. By titration with $N/2$ H_2SO_4 and methyl orange the solution showed 24.7 per cent Na_2O and 75.30 per cent water. Amount taken, 90 grams, which accordingly contained $90 \times 0.247 = 22.23$ grams Na_2O and $90 \times 0.753 = 67.77$ grams water. There was also added 20 c. c. water, making the total water used 87.77 grams.

The dip accordingly contained:

	Grams.	Per cent.
Water	87.77	8.78
Soda (Na_2O)	22.23	2.22
Rosin	220.00	22.00
Phenols	120.00	12.00
Hydrocarbons and pyridin	550.00	55.00
	1,000.00	100.00

Saponification was effected in a flask connected with a reflux condenser and immersed in a water bath.

Analysis of dip No. 1 gave:

	A.	B.	Mean.
	Per cent.	*Per cent.*	*Per cent.*
Water	8.8	8.6	8.7
Soda	2.15	2.17	2.16
Pyridin	1.19	1.30	1.25
Phenols	11.78	11.74	11.76
Rosin acids, gravimetric	19.90	19.80	19.85
Rosin acids, volumetric	(1)20.03 (2)19.97	(1)19.94 (2)19.81	19.94

It will be noted that, as was to be expected, the amount of rosin acids found is about 90 per cent of the rosin used in the dip. The results seemed very satisfactory, except perhaps in the case of the phenols. (But see page 35.)

Dip No. 2.—Made up more as a dip would be made in practice. Rosin, 200 grams.

Coal-tar oils which were used gave on analysis:

	A.	B.	Mean.
	Per cent.	*Per cent.*	*Per cent.*
Water	0.40	0.50	0.45
Pyridin	3.35	3.56	3.45
Phenols	20.30	20.40	20.35
Hydrocarbons, by difference	75.95	75.54	75.75
	100.00	100.00	100.00

Amount taken, 700 grams, which would give:

	Grams.
Water	$700 \times 0.0045 = 3.15$
Pyridin	$700 \times .0345 = 24.15$
Phenols	$700 \times .2035 = 142.45$
Hydrocarbons	$700 \times .7575 = 530.25$

Soda and water: By titration with $N/2$ H_2SO_4 and methyl orange the solution was found to contain 25.22 per cent Na_2O and 74.78 per cent H_2O. Ninety grams of the solution were employed, giving 22.7 grams Na_2O and 67.3 grams H_2O. There was also added 10 c. c. of water. The materials were all put together in a 1,500 c. c. flask and the latter was stoppered and shaken frequently until saponification was complete, with application of no external heat.

The dip accordingly contained:

	Per cent.
Water (0.32+6.73+1.0)	8.05
Soda (Na_2O)	2.27
Pyridin	2.42
Rosin	20.00
Phenols	14.25
Coal-tar hydrocarbons	53.01
Total	100.00

Analysis gave the following results:

	A.	B.	Mean.
	Per cent.	*Per cent.*	*Per cent.*
Water	8.10	8.30	8.20
Soda	2.28	2.26	2.27
Pyridin	2.28	2.21	2.25
Rosin acids	[a] 18.66	[b] 18.80	18.73
Phenols	14.16	14.06	14.11
Hydrocarbons, by difference	54.52	54.37	54.44
	100.00	100.00	100.00

[a] Volumetric.

[b] Gravimetric.

Results from this dip appear very satisfactory. It should be noted that the formulas employed in the experimental dips are in no way recommended for actual use. The immediate object was not to make a superior dip, but merely to test the methods of analysis employed.

TEST WITH CRESYLIC ACID DIP OF KNOWN COMPOSITION.

The next experiments were to test in the same way the validity of the methods when applied to cresylic acid dips. Dip No. 3 was accordingly made somewhat along the lines of the U. S. P. formula for liquor cresolis compositus.

One hundred and seventy-five grams of linseed oil was saponified in a beaker with 81 grams of a solution of pure KOH, shown by titration with N/2 H_2SO_4 and methyl orange to contain 35.9 per cent of K_2O and 64.1 per cent H_2O. Accordingly $81\times0.359=29.08$ grams K_2O, and $81\times0.641=51.92$ grams H_2O were introduced. The beaker with its contents was weighed before and again after saponification, and a loss of 3.5 grams noted, leaving in the soap finally $51.92-3.5=48.42$ grams of H_2O. The materials employed in the soap were then—

	Grams.
Linseed oil	175.00
Potash (K_2O)	29.08
Water	48.42
Total	252.5

Now, taking as the mean molecular weight of the fat acids of linseed oil the number 284.7,[a] and as the molecular weight of glycerin the number 92, the mean molecular weight of linseed oil will be $3(284.7)+92-54=892.1$. The 175 grams of linseed oil will then be equivalent to—

Glycerin, $175\times\frac{92}{892}=18.03$ grams.

Fatty acid anhydrids, $175\times\frac{854-27}{892}=162.25$ grams.

But this glycerin will take up $18.03\times\frac{54}{184}=5.28$ grams H_2O in the process of saponification of the linseed oil, hence the completed soap theoretically consists of—

	Grams.
Glycerin	18.03
Fatty acid anhydrids	162.25
K_2O	29.08
Water (48.42—5.28)	43.14
Total	252.50

The soap was transferred to a tared liter flask with the aid of U. S. P. cresylic acid (cresylic acid from two different manufacturers being mixed in equal parts to secure a fair sample), the contents were brought to 500 grams with cresylic acid, and the flask was stoppered and frequently shaken for several days till a uniform, clear liquid resulted. The mean of four analyses (page 34) showed the U. S. P. cresol employed to be 98.80 per cent pure. The amount used was 500—252.5=247.5 grams, containing accordingly 247.5×0.988=244.53 grams phenols and 247.5×0.012=2.97 grams of pyridin, hydrocarbons, etc.

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[a] Lewkowitsch, J. Chemical Technology and Analysis of Oils, Fats, and xes, 3d Ed., vol. 1, p. 334. 1904.

Analysis of the dip ought then to show:

	Per cent.
Water	8.63
K_2O	5.82
Fatty acid anhydrids	32.45
Glycerin	3.61
Phenols	48.90
Pyridin, hydrocarbons, etc	0.59
Total	100.00

Actual analysis of this dip gave the following results:

	A.	B.	Mean.
Water	8.1	8.0	8.06
K_2O	5.71	5.72	5.71
Fatty acid anhydrids	31.50	31.39	31.45
Glycerin	3.50	3.49	3.50
Phenols	48.77	48.98	48.88
Pyridin	0.28	0.28	0.28

TESTS FOR NONVOLATILE ACID BODIES IN COAL-TAR CREOSOTE AND COMMERCIAL CRESYLIC ACID.

Mention has already been made of the fact (page 24) that both coal-tar oils and commercial cresylic acid may contain bodies of an acid nature, absorbed by caustic soda solution with a consequent increase in its volume, but which are not volatile with steam at 100° C. These acid bodies very probably vary in amount in different samples of oils and cresols, and may not be present in every case. Examinations were made of the coal-tar creosote oil employed in making dip No. 2, and of the U. S. P. cresol used in dip No. 3.

The coal-tar creosote oil used in preparing dip No. 2 was found to contain by distillation of the oil with steam 20.35 per cent phenols, as the mean of the two results 20.30 per cent and 20.40 per cent. The oils were then handled in another way, namely, 100 grams were distilled from an Engel flask to 300° C. The first portion of the distillate containing water was received in a small stoppered cylinder, benzol and NaCl were added, the cylinder was shaken, and after separation had taken place the benzol was pipetted out and added to the rest of the distillate. Extraction of the aqueous portion was repeated several times in the same way. The total oily distillate was made to a definite volume with benzol, an aliquot part shaken with caustic soda in the measuring tube and the increase in volume noted. Somewhat variable results were obtained, ranging between 21.80 and 23.20 for the per cent of phenols found by this method in the creosote oil.

In the examination of the U. S. P. cresol used in dip No. 3 weighed amounts of the cresol were introduced into a 150 c. c. separatory funnel, with 15 c. c. of 1:2 NaOH and 30 to 40 c. c. water, then benzol and H_2SO_4 added, and, in short, the last two steps of the adopted analytical method were followed in detail until the phenols were brought to measurement.

Treated in this way 9.059 grams cresol gave 9.13 c. c. increase in volume of NaOH=100.77 per cent phenols; 8.146 grams cresol gave 8.15 c. c. increase in volume of NaOH=100.05 per cent phenols. The U. S. P. cresol will then appear by this method to contain 100.41 per cent phenols, the mean of the two results obtained.

Phenols were now determined exactly as they would be in a dip, by steam distillation of weighed amounts of the U. S. P. cresol.

Weight cresol.	Increase in volume NaOH.	Per cent phenols.
Grams.	*Grams.*	
9.457	9.40	99.40
9.590	9.46	98.64
9.468	9.36	98.86
9.105	8.95	98.30

The mean of these results is 98.80 per cent, while the range of difference between the results is about 1 per cent of the amount of phenols operated upon. When working with nearly pure phenols it is difficult to obtain results which check as closely as desirable, for the meniscus is subject to considerable variation in shape and degree of curvature. This variation in the form of the meniscus appears to a less extent when the phenols from a cresol dip are measured, and is practically absent in case the phenols have been obtained from a creosote dip, hence readings in these cases check more closely. In practice results may reasonably be expected to check within this limit of 1 per cent of the total amount of phenols in all cases; that is, results on a cresol dip containing 50 per cent phenols agree within 0.5 per cent, and those on a creosote dip containing about 10 per cent phenols within 0.1 per cent.

It is accordingly evident that both coal-tar creosote oils and even quite pure cresylic acid may contain bodies of an acid nature, which may possibly be phenoloids, but for the determination of which, since they are not volatile with steam, there appears at present no possible means. In the actual analysis of a dip these bodies will naturally tend to increase the percentage of rosin acids found, whether the latter are determined gravimetrically or volumetrically. It is not likely, however, that in any case the percentage of rosin acids will be thus increased to a figure greater than the per cent of rosin actually employed in making the dip, as is indicated by the result for rosin acids obtained in the analysis of dip No. 2. As already shown, the creosote oil used in this dip contained a considerable amount of nonvolatile acid bodies. The existence of these nonvolatile acid bodies was not known at the time dip No. 1 was made and analyzed. Unfortunately, no more of the purified cresylic acid used for that dip was available for examination; but inasmuch as it was prepared from a very crude commercial product, it undoubtedly contained an appreciable amount of these nonvolatile acid bodies, whose presence may account for the somewhat low results for phenols obtained in the analysis of that dip.

SUMMARY.

In conclusion certain points may be emphasized:

1. Methods appear now available for determining with considerable accuracy the constituents of coal-tar creosote and cresylic acid dips. These methods are not especially tedious, nor, while requiring a certain amount of practice for their successful execution, do they demand complicated apparatus, exceptional skill in manipulation, or the liberal use of expensive chemicals. The results are all obtained by fairly simple volumetric processes, and the closeness with which experience in this laboratory has shown them to check, whether obtained by the same or different operators, renders the methods herein described particularly adapted to the standardization of dips.

2. Methods exactly parallel to the methods employed in the analysis of dips may be applied to the valuation of creosote oil and cresylic acid which are to be used in making dips. If a dip is properly made from analyzed materials and the dip itself then analyzed, the actual analysis of the dip will agree very closely with its calculated composition. The validity of the methods of analysis is thus doubly confirmed.

3. Furthermore, the agreement between the analysis of a dip made from analyzed materials with its calculated composition indicates that it is actually possible for a manufacturer to place on the market a dip of practically unvarying composition.

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U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 108.

A. D. MELVIN, CHIEF OF BUREAU.

FEEDING FOR MEAT PRODUCTION.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., August 22, 1908.

Sir: I have the honor to transmit herewith, and to recommend for publication as a bulletin of this Bureau, a manuscript entitled "Feeding for Meat Production," by Dr. Henry Prentiss Armsby, who is in charge of the investigations in animal nutrition which have been in progress for some years at The Pennsylvania State College Agricultural Experiment Station by cooperation between that station and this Bureau. The paper consists of a general discussion of the principles underlying feeding for meat production, and while, as stated by Doctor Armsby, it does not include a report of any original work, it is believed that such a compilation may be useful in showing more clearly the practical bearings of the investigations mentioned.

Respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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FEEDING FOR MEAT PRODUCTION.

GENERAL PRINCIPLES.

DEFINITIONS.

By "meat" we understand in a general way the flesh of an animal as distinguished from the skeleton on the one hand, and the internal organs, hide, and other offal on the other hand. Meat in this general sense is separable mechanically into fat tissue and lean meat, both of these, but especially the latter, being of somewhat complex composition.

FAT TISSUE.

Description.—Fat tissue, or "adipose tissue," consists essentially of cells of connective tissue in which a large accumulation of fat has taken place, the protoplasm of the cells being reduced to a mere envelope surrounding the fat. These fat cells are held together by a basis of vascular connective tissue. Cells of this sort are found in almost all parts of the body, but there are two regions in which fat especially tends to accumulate and which constitute the great reserves of fat in the body, (1) the subcutaneous tissue, and (2) the connective tissue surrounding the internal organs, particularly the intestines and kidneys.

Composition.—Fat, of course, is the chief ingredient of adipose tissue, but the connective tissue and the remnants of protoplasm, which, together with adhering fat, yield the "cracklings" when the fat is melted out, make up an appreciable portion of its mass. Thus Henneberg, Kern, and Wattenberg[a] found the fat tissue from various parts of the fat sheep to contain from 85.33 to 90.35 per cent of fat. In later experiments with five lambs the same investigators[b] obtained the following average figures, to which the writer has added the energy content computed on the assumption that the fat-free dry matter consisted of protein:

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[a] Journal für Landwirtschaft, bd. 26, p. 381.

[b] Ibid., bd. 28, p. 289.

Composition of fat of lambs and computed energy value.

Constituent.	Subcutaneous fat.	Kidney fat.	Intestinal fat.
Water ... per cent..	11.00	4.36	5.82
Fat ... do....	84.49	93.89	92.15
Fat-free dry matter ... do....	4.51	1.75	2.03
Total ... do....	100.00	100.00	100.00
Computed energy value per kilogram ... calories..	8,283	9,019	8,870

Beythien[a] reports the following extremes of composition of the fat tissue of commercial fresh beef, pork, and mutton:

Constituent.	Minimum.	Maximum.
	Per cent.	*Per cent.*
Water	5.04	18.73
Fat	76.10	93.02
Nitrogenous matter	1.84	4.97
Ash	.10	.23

LEAN MEAT.

Description.—The lean meat is still more complex in its make-up. Primarily it consists of muscular tissue. A muscle is briefly described by Foster[b] as consisting of "elementary muscular fibers, bound together in variously arranged bundles by connective tissue which carries blood vessels, nerves, and lymphatics." All these structural elements, speaking broadly, may be said to be protein in their general character, and the same is true of the connective tissue lying between the various muscles as well as of the tendons which form their attachments to the bones.

In addition to these proteid structures, however, muscular tissue contains more or less fat. Globules of this substance are found in the muscular fibers themselves, nor are there lacking indications that the complex protoplasm of the cell may contain fat in actual chemical combination with protein material. By far the larger part of the fat of the muscles, however, is to be found in the connective tissue in the form of the fat cells already described. In other words, larger or smaller masses of adipose tissue are formed between the muscles, the muscular bundles, or even between the single muscular fibers.

What we commonly speak of as lean meat, then, has a composition varying more or less according to the proportion of actual muscular fibers and of connective and vascular tissue, but especially with the extent to which fat deposition has taken place.

---

[a] Biedermann's Central-Blatt für Agrikulturchemie und rationellen Landwirtschafts-Betrieb, bd. 30, p. 683.

[b] Text Book of Physiology, 1898, p. 82.

Composition.—Few analyses of the lean meat freed from adhering fat are on record, and its variations in composition may be considered more profitably in another connection. The following analyses by Jordan[a] of the meat from the entire carcasses of well-fed steers respectively 17 and 27 months old, the fat having been removed as fully as possible mechanically, may serve to indicate in a general way the composition of what might be called commercial lean meat. The figures are, in each case, the average for two animals, and the energy values have been computed by the present writer.

Average composition of lean meat of steers, and computed energy values.

Constituent.	In fresh meat.		In dry matter.	
	17 months old.	27 months old.	17 months old.	27 months old.
Water....per cent..	70.01	70.09	....	....
Ash....do....	.96	.95	3.19	3.18
Protein (by difference)....do....	19.83	19.30	66.15	64.53
Fat....do....	9.20	9.66	30.66	32.29
Total....do....	100.00	100.00	100.00	100.00
Computed energy value per kilogram....calories..	2,004	2,018	6,683	6,746

According to these figures, about two-thirds of the dry matter of lean beef consists of protein and somewhat less than one-third of fat.

PROPORTIONS OF FAT AND LEAN IN CARCASS.

The proportion of lean meat to fat tissue in the carcass is naturally quite variable, depending somewhat upon the age, but chiefly on the feeding of the animal, insufficient nutrition reducing the store of fat in the body to a minimum, while heavy feeding may cause the production of large amounts of it. Thus Lawes and Gilbert found the proportion of fat in the whole bodies of 10 farm animals to vary from 8.7 per cent in a well-fed ox to 42.3 per cent in a fat hog. Atwater[b] reports the following as the average composition of a side of beef of medium fatness:

Average composition of a side of beef of medium fatness.

	Per cent.
Water....	54.77
Protein....	17.20
Fat....	27.07
Ash....	.96
Total....	100.00

Lean cuts of meat, however, may contain much less fat than is indicated by the above statement. Thus Grindley and Emmett[c] analyzed seven samples of beef round from which the visible fat had been removed, the average of the seven analyses being as follows:

---

[a] Maine Experiment Station, Report for 1895, Vol. II, pp. 36–77.

[b] U. S. Department of Agriculture, Office of Experiment Stations, Bulletin 21, p. 35.

[c] U. S. Department of Agriculture, Office of Experiment Stations, Bulletin 162.

Average compostion of seven samples of beef round with visible fat removed.

Constituent.	Fresh substance.	Water-free substance.
	Per cent.	*Per cent.*
Water	73.30	....
Ash	1.13	4.27
Protein	18.79	70.67
Extractives	2.98	11.07
Fat	4.88	17.81

The minimum figure for fat was 3.19 per cent in the fresh substance, or 12.29 per cent of the dry matter.

Voit[a] found in the carefully prepared lean meat which he used as representing substantially protein food, and which had been most painstakingly freed from all visible fat, 0.91 per cent of ether extract in the fresh substance, equal to 3.77 per cent of the dry matter.

The term "meat" commonly suggests to the mind the muscular tissue of the animal, and has become almost synonymous with a proteid diet. It is evident, however, that the commercial growing of meat involves the production of considerably more fat than protein, and that in so far as this fat is actually consumed meat is far from being the distinctively protein food which it is ordinarily considered. Thus the so-called "nutritive ratio" of the above-mentioned side of beef, calculated in the usual manner, is about 1 to 3.5. On the other hand, however, it is equally true that the protein ingredients of meat are the distinctive ingredients for the sake of which meat is produced and eaten, while the fat, although a valuable nutrient, is to a certain extent subsidiary and accidental.

PROCESSES INVOLVED IN MEAT PRODUCTION.

Corresponding in a general way to the two main ingredients of meat—protein and fat—we may say that there are two physiological processes involved in its commercial production, namely, growth and fattening.

GROWTH.

The animal at birth is usually regarded as unfit to serve as human food. Moreover, even were this not the case, it would be in the highest degree uneconomic to fail to utilize the marked assimilative powers of the young animal in the production of body tissue (meat) from food. Consequently the production of meat involves more or less growth in all cases. This may, for special reasons, be concluded early, as in the production of lamb or veal, but as a whole the world's supply of meat is derived from animals at least approaching maturity. This growth of animals from birth to approximate maturity consists essentially of an increase in the proteid tissues.

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[a] Zeitschrift für Biologie, bd. 1, p. 95.

FATTENING.

The production of protein tissue during growth is normally accompanied by the production of more or less fat tissue, its amount depending largely on the nature and quantity of the feed. Experience has shown that the tenderness and palatability of the lean meat are notably greater when it is accompanied by considerable fat, and also that this improvement in quality may be effected by a comparatively short period of high feeding after growth has been substantially completed. It has become customary, therefore, to a large extent, to separate the business of meat production into two branches, conducted by different sets of individuals, one breeding animals and raising them until nearly mature and selling them to the other to be fattened.

It is obvious, however, that no sharp line can be drawn between the processes of growth and fattening. A calf or yearling may be fattened while growing, and a 2-year-old steer will continue to grow to some extent while being fattened. The two processes shade into each other, and economic considerations will decide whether they shall be carried on more or less simultaneously by a single producer or at different times by two different individuals.

LAWS OF GROWTH.

In any case it is clear that growth is the fundamental process in meat production, determining substantially the amount of meat in the narrower sense, while fattening affects chiefly its quality. We naturally take up first, then, a consideration of the laws of growth.

Growth may be defined briefly as consisting in an increase of the structural elements of the body, chiefly by cell multiplication, resulting in a gain in size and weight. Since these structural elements are mainly protein in character, this conception of growth makes it equivalent to an increase in the protein tissue of the body (including, of course, the mineral ingredients of the latter). In other words, any accompanying fat production, although in a sense involving growth of adipose tissue, may from this point of view be regarded as incidental. The actual processes of growth are substantially the same whether we produce fat lambs or veals or the lean and muscular colt or dairy calf.

RATE OF GROWTH.

Before proceeding to a discussion of the laws governing growth, it is important to consider the method of expressing the facts observed.

If we were to plat the successive weights or dimensions of a growing animal we should obtain what might be called the curves of weight or of stature. These rise rapidly at first and afterwards more slowly as the animal approaches maturity. Or we may plat in like manner the increments of weight or size observed in successive equal periods (day, week, month, or year), thus showing at what periods the absolute growth is most rapid.

It is evident, however, that an increase of a pound in weight by an animal weighing 500 pounds is relatively much less than the same increase in a 100-pound animal. A better expression of the processes of growth is afforded by a computation of the rate of growth, by which is meant the increment in a given unit of time expressed as a fraction of the amount at the beginning of that time. Thus in the instance just supposed the rate of growth in weight would be in the first case one five-hundredth and in the second one one-hundredth. In the second case the small animal is growing five times as fast as the larger, in proportion to its weight, and may be regarded as showing five times the energy of growth. An evident advantage of this manner of expressing the growth is that it permits of a comparison of animals of very different weights, as, for example, sheep with cattle.

INFLUENCE OF AGE ON RATE OF GROWTH.

Somewhat extensive observations, both on man and the lower animals, show that the average rate of growth as above defined diminishes from birth onward, the diminution being more rapid at first and slower as maturity is approached. This subject has recently been discussed in a most illuminating manner by Minot [a] on the basis of his own and others' observations on guinea pigs, rabbits, chicks, and other animals, as well as on man. Graphically the rate of growth is expressed by a descending curve, steep at first, but gradually becoming more and more nearly horizontal. Apparently, too, the same curve extends backward without material break into intra-uterine life. Foster says: "It seems as if the impetus of growth given at impregnation gradually dies out." In the early stages of growth, therefore, the anabolic processes, which tend to build up tissue, predominate, while as time goes on the katabolic processes gain more and more over the anabolic until at maturity the two tend to become substantially balanced.

Moreover, as the following paragraphs will show, what is true of the rate of growth as measured by size or weight is also true of growth in the stricter sense as defined in the opening paragraph, i. e., the rate of increase of protein tissue. Indeed, as we shall see later, the increase in weight of the young, growing animal is to a large extent synonymous with the growth of such tissue.

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[a] Popular Science Monthly, vol. 71 (1907), p. 193.

Percentage of feed protein retained in the body.—It has been shown that in the mature animal the katabolism of protein substantially keeps pace with its anabolism. Any considerable increase in the protein supply in the feed fails to cause a corresponding storage of protein in the body, but simply increases the amount broken down, resulting in a correspondingly increased excretion of nitrogenous metabolic products. Indeed, this is really implied in the conception of maturity. By a mature animal we mean one that has completed its growth, and growth consists essentially in the increase of the nitrogenous structural elements of the body. Obviously, therefore, if the capacity for growth has been exhausted, we should expect no material storage of protein, but that an excess of this material would serve chiefly or wholly as a source of energy to the organism.

With the young animal the case is different. Its rapidly growing cells and tissues demand a liberal supply of protein, and if this is afforded by the feed it will be largely utilized to build up tissue instead of undergoing nitrogen cleavage, and consequently a much larger percentage of the feed protein will be retained in the body. This difference between the protein metabolism in immature and mature animals is most readily shown by a comparison of the amount of feed protein with the amount stored in the body. Some of the more important data regarding domestic animals follow.

Soxhlet's well-known experiments on calves[a] afford interesting data on this point, which are summarized in the following table, the feed consisting of fresh whole milk:

Percentage of feed protein stored.

Animal.	Age.	Digested protein (N. ×6.25) of feed per day.	Daily gain of protein (N. ×6 25) by animal.	Digested protein stored.
	Days.	*Grams.*	*Grams.*	*Per cent.*
A	16–19	171.3	129.1	75.3
	30–33	228.4	163.6	71.6
B	15	330.8	231.8	70.1
	21	317.5	216.1	68.1
C	8	262.4	202.0	77.0

An investigation by Neumann[b] upon the influence of calcium phosphate and calcium carbonate on the metabolism of a calf somewhat older than Soxhlet's animals yielded the following figures for the daily nitrogen balance:

---

[a] Erster Bericht über Arbeiten der K. K. Landwirtschaftlich-Chemische Versuchsstation in Wien, 1870–77, pp. 101–155.

[b] Journal für Landwirtschaft, bd. 41, p. 343; bd. 42, p. 33.

Daily nitrogen balance.

Period.	Average age.	Feed.	Nitrogen digested.	Daily gain of nitrogen.	Digested nitrogen retained.
First series:	*Days.*		*Grams.*	*Grams.*	*Per cent.*
I	40	Skim milk	68.70	33.47	48.71
II	45	Skim milk+$Ca_3(PO_4)_2$	69.41	29.44	42.40
Second series:					
I	57	Skim milk	74.82	31.25	41.78
II	62	Skim milk+$CaCO_3$	73.86	23.12	31.30
III	69	Skim milk	77.60	27.88	35.92

Disregarding for our present purpose the relatively small effects produced by the calcium salts, it is evident that the results are in general accord with Soxhlet's, although the percentage stored is notably lower.

De Vries Jzn [a] conducted a series of digestion and metabolism experiments on calves at the Göttingen Experiment Station and obtained the following results for the protein metabolism:

Protein metabolism of calves.

Animal.	Period.	Average age.	Average live weight.	Feed per day.	Protein (N. × 6.25) per day.		
					Digested.	Stored in body.	
		Days.	*Kilos.*		*Grams.*	*Grams.*	*Per cent.*
A	I	50	82.39	14 kilograms skim milk	429.0	128.7	30.0
	II	65	94.96	7 kilograms skim milk 8 kilograms whole milk	425.3	170.4	40.1
	III	74	100.67	13.95 kilograms skim milk	428.3	117.6	27.5
	IV	100	119.94	14 kilograms skim milk 300 grams starch	398.1	148.9	37.4
B	I	38	82.00	14 kilograms skim milk	404.0	181.39	44.9
C	I	37	70.50	do	395.8	167.09	42.2
	II	64	88.60	do	[b] 386.9	111.56	28.8
D	I	45	69.29	9 kilograms whole milk	[b] 241.1	156.50	64.9
	II	63	81.38	9 kilograms whole milk+260 grams starch.	[b] 230.9	102.50	44.4
	III	74	85.71	9 kilograms whole milk	[b] 239.4	126.9	52.5

Wilson [c] fed three new-born pigs for sixteen days on skimmed cow's milk either alone or with addition of lactose and dextrose, respectively. The gains were determined by a comparison of the weight and composition of the animals with those of three other pigs of the same litter at the beginning of the experiment. Results of similar earlier experiments by Sanford and Lusk are also reported. For protein the results were as follows:

---

[a] Untersuchungen über die Fleischbildung des Saugkalbes. Inaugural Dissertation. Göttingen, 1896, p. 52.

[b] Digestibility estimated.

[c] The American Journal of Physiology, vol. 8, p. 197.

Storage of protein by new-born pigs.

Experimenter.	Feed.	Average age of animal.	Feed protein stored.
		Days.	*Per cent.*
Wilson	Skim milk	8	35.6
	Skim milk+lactose	8	44.5
	Skim milk+dextrose	8	42.1
Sanford and Lusk	Skim milk	7	23.0
	Skim milk+lactose	7	38.0
	Skim milk+dextrose	7	48.0

Investigations by Tschirwinsky[a] upon the sources of fat in pigs in which the gains of the animals were determined by means of comparative slaughter tests, gave the following results for the gain of protein between the ages shown:

Gain in protein by young pigs as shown by slaughter tests.

Animal.	Age.	Protein digested.	Protein gained.	Proportion of digested protein stored.
		Grams.	*Grams.*	*Per cent.*
No. 2	10 to 28 weeks	7,494	1,552	20.7
No. 3	9 to 22 weeks	3,554	1,193	33.6

Results of the same general character have been obtained in numerous experiments with infants, as for example those of Lange.[b]

Of experiments with somewhat older animals may be mentioned two with lambs by Henneberg, Kern, and Wattenberg and by Weiske, respectively.

The first of these investigations[c] had for its main object a study of the economy, from the point of view of meat production, of a fattening as compared with a growing ration for lambs. Two uniform lots of six lambs each were used. Lot 1 received a good growing ration for four periods, followed by a fattening ration in the fifth period, while lot 2 received a fattening ration from the start and was ready for the butcher at the end of the third period. Sample animals from each lot were slaughtered at the beginning and at intervals during the experiment and the carcasses partially analyzed. The results afford data for computing the gain of protein in the form of muscular tissue and the gain of total fat, but not, directly, the gain of total protein. Assuming the latter, however, to be 20.5 per cent of the fat-free body, the percentage of digestible protein retained in the body (not including the wool) was as follows:

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[a] Die Landwirtschaftlichen Versuchs-Stationen, bd. 29, p. 317.

[b] Atwater and Langworthy. Digest of Metabolism Experiments. U. S. Department of Agriculture, Office of Experiment Stations, Bulletin 45, pp. 30 and 326.

[c] Journal für Landwirtschaft, bd. 28, p. 289.

Gain in protein by lambs on growing and fattening rations for varying periods.

Lot.	Period.	Approximate average age.	Proportion of protein stored.
		Months.	*Per cent.*
1	I and II	9	7.73
	III and IV	21	4.06
	V	24	3.04
2	I and II	9	7.98
	III	15	2.54

Weiske's investigations[a] were upon two Southdown-Merino lambs about 4 months old, which were fed a good growing ration for about eleven months, this time being divided into nine periods of approximately equal length. After an interval of eight months a tenth period was added. In each period, usually during the last sixteen days, the balance of nitrogen, sulphur, and ash was determined. Owing to various irregularities and accidents, the conclusions are based chiefly upon the results on one animal (No. 2) except in Periods II and X.

The daily growth of wool is estimated to have contained 0.53 gram of nitrogen. Deducting this from the total gain observed gives the following results:

Nitrogen digested and retained by lambs on a growing ration.

Period.	Nitrogen per day and head.		
	Digested.	Retained in body.	
	Grams.	*Grams.*	*Per cent.*
I	12.04	2.17	18.02
II	13.05	2.05	15.71
III	12.94	1.62	12.52
IV	14.39	2.31	16.05
V	13.27	1.61	12.13
VI	12.92	1.53	11.84
VII	13.07	2.34	17.90
VIII	12.72	1.97	15.49
IX	11.98	0.39	3.26
X	11.18	1.59	14.22

Jordan's investigations[b] upon the relation of feed to the growth and composition of the bodies of steers afford data for comparing feed protein with protein gain in steers between the ages of 23 and 33 months. The gain of protein is computed from the weight and composition of the carcasses of similar animals at the two ages given, while the digestible protein of the feed is computed from the known[a] total protein on the assumption of average digestibility. Comparing No. 2 with No. 1 and No. 3 with No. 4, the average daily results, not including the protein of the hides, were as follows:

---

[a] Landwirtschaftliche Jahrbücher, bd. 9, p. 205.

[b] Maine Experiment Station, Report for 1895, vol. 2, pp. 36–77.

Comparison of average daily feed protein with protein gain.

Animal.	Protein digested.	Protein gained.	Digested protein stored.
	Pounds.	*Pounds.*	*Per cent.*
Steer No. 2	1.96	0.0971	4.97
Steer No. 3	1.05	.1123	10.72

Steer No. 2 had been fed for the preceding seventeen months on a ration considerably richer in digestible protein than that of steer No. 3.

Rate of gain of protein.—The foregoing results amply substantiate the introductory statement that in the very young animal a relatively large proportion of the feed protein may be retained in the body, and likewise show that this proportion diminishes rather rapidly as the animal grows older. The comparison, however, is likely to be disturbed by variations in the amount of protein fed. Since we may fairly suppose that the demand for protein at any given age is relatively fixed and independent of the supply, an excess of protein in the feed would obviously tend to reduce the percentage retained.

A more philosophical method of comparison is to compute the rate of gain of protein at different ages—that is, to compare the increment of protein during any given period with the amount contained in the body at the beginning of that period.

In those of the foregoing investigations in which control animals were analyzed at the beginning of the experiments we have an approximately correct measure of the original stock of protein in the bodies of the animals experimented on. Where no control animal was analyzed the attempt has been made to secure an approximate basis for computation by estimating the original stock of protein in the body from the live weight. For this purpose Lawes and Gilbert's figures for a fat calf have been used, but the percentage of fat has been reduced one-half, giving the following as the assumed composition:

	Per cent.
Water	69.54
Ash	5.17
Protein	17.76
Fat	7.53
Total	100.00

Having thus secured a starting point, it is easy to compute the stock of protein contained in the body at the end of each succeeding period, and likewise the average daily increment during each period expressed as a percentage of the amount present at the beginning of the period. Where there are intervals between the periods, the average rate of gain of each period has been assumed to continue until the beginning of the next. Arranging the results in the order of age, and without reference to species of animal, we have the results contained in the table which follows.

---

[a] Or estimated in the case of the hay.

In the majority of these cases the initial protein content of the body was estimated from the live weight. It seems desirable also to compute the gain of protein per 1,000 pounds live weight. Except in the case of very fat animals, the results are likely to correspond substantially with those computed in the other way, while they have the advantage of being expressed in the manner usually adopted for expressing feeding requirements. This, of course, assumes that the protein requirement is proportional to weight, and not to surface, like the total feed requirement, an assumption which seems at least probable and which eliminates the element of varying size of animal.

Rate of gain of protein by animals of different ages.

Average age of animal.	Experimenter.	Animal.	Daily gain of protein.	
			Computed on total protein of body.	Computed per 1,000 pounds live weight.
Days.			*Per cent.*	*Pounds.*
7	Sanford and Lusk	Pig	7.269	5.621
8	Wilson	do	6.852	5.757
8	Soxhlet	Calf	2.347	3.994
15	do	do	2.076	3.552
18	do	do	1.644	2.803
21	do	do	1.722	3.024
32	do	do	1.693	2.755
37	De Vries Jzn	do	1.335	2.276
38	do	do	1.246	2.124
40	Neumann	do	1.795	2.945
45	do	do	1.449	2.419
45	De Vries Jzn	do	1.272	2.169
50	do	do	.880	1.500
50	Neumann	do	1.082	1.844
54	do	do	1.026	....
57	do	do	1.320	2.284
62	do	do	.939	1.611
63	De Vries Jzn	do	.678	1.209
64	do	do	.655	1.209
65	do	do	1.020	1.723
69	Neumann	do	1.062	1.823
74	De Vries Jzn	do	.713	1.271
100	do	do	.711	1.192
114	Tschirwinsky	Pig	.442	.663
134	do	do	.483	.740
140	Weiske	Lamb	.372	.651
177	do	do	.307	.499
214	do	do	.219	.360
254	do	do	.288	.449
290	Henneberg	do	.272	.303
293	Weiske	do	.179	.284
328	do	do	.160	.264
366	do	do	.232	.382
405	do	do	.178	.301
436	do	do	.033	.061
458	Henneberg	do	.068	.074
521	do	do	.087	.096
745	do	do	.067	.069
840	Jordan	Steer	.064	.089

It is perfectly obvious that the range of possible error in the single results obtained in this way is very considerable. Nevertheless the general teaching of the table is perfectly clear, viz, that the rate of growth of protein tissue, whether expressed per unit of body protein or per 1,000 pounds live weight, is relatively high in the new-born animal and decreases rapidly at first and more slowly later, tending to be asymptotic to the zero line. In other words, we obtain, as might have been anticipated, a curve quite similar to those expressing the rate of increase in weight or in stature.

If we let g equal gain of protein per day per 1,000 pounds live weight and a equal age in days, we find that a curve represented by the empirical equation[a]—

$$g = \frac{135}{a+20}$$

corresponds fairly well with the general average of the observed results. This is shown clearly by figure 1, in which the individual results recorded in the foregoing table are indicated by the dots, while the lower curve of the diagram is that represented by the above equation. Of course, considerable individual variations are to be expected, and no particular significance attaches to the mathematical form of the curve, but it would seem that we may tentatively use this formula as expressing in a broad general way the average protein growth at different ages.

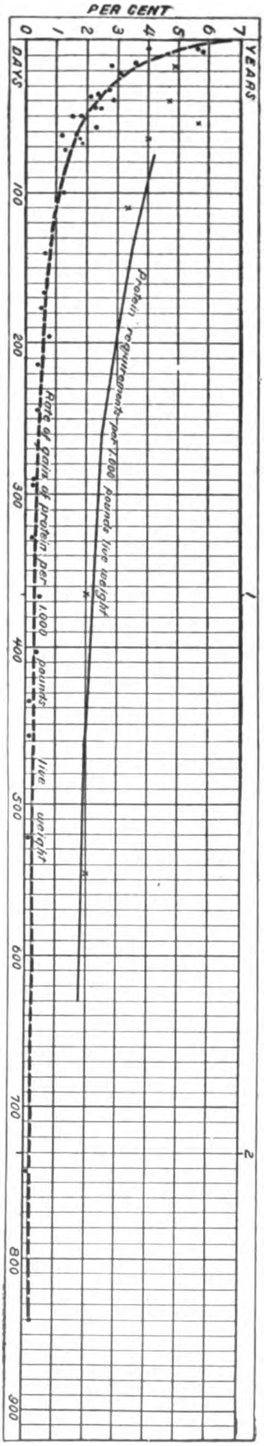

FIG. 1.—Diagram showing protein requirements and rate of gain of protein in growing animals.

Gain of protein by mature animals.—While it is true that the larger share of the feed protein supplied to a mature animal undergoes nitrogen cleavage, and that consequently the protein katabolism of such an animal is chiefly determined by the protein supply, the statement that the mature animal does not produce protein tissue needs modification.

In the first place, of course, the epidermal tissues (hair, wool, etc., hoofs, horns, and epidermis proper) are continually growing and serve to store up a rather small amount of nitrogenous matter. Henneberg and Stohmann[a] estimate the nitrogen in the daily growth of hair in cattle at 1.5 to 4.5 grams, and Armsby and Fries[b] have obtained corresponding results. For sheep, quite varying figures have been obtained for the growth of wool. Some few data are also available on the growth of the feathers of geese.

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[a] The equation of a rectangular hyperbola.

In the second place, the deposition of large amounts of fat in the body would perhaps involve the growth of more or less connective tissue, and while the percentage of nitrogen in fat tissue is small, it is not impossible that it may sensibly affect the nitrogen balance. Thus if we assume adipose tissue to have the average composition shown on page 8, the formation *de novo* of 1 kilogram of such tissue would be equivalent to the storage of 4.6 grams of nitrogen. To what extent such a gain of fat represents a new growth of connective tissue and to what extent a storage of fat occurs in preexisting connective tissue there appear to be no data to decide.

Finally, it should be remembered that in many of the older metabolism experiments there is the probability of some loss of excretory nitrogen having occurred, either through incomplete collection of the excreta or especially by volatilization during the preparation for analysis. All these factors are relatively small, however, but there is another and much more important consideration. If we supply a mature animal with a diet deficient in protein or deprive it of food altogether, it is a familiar fact that it may live and continue to perform the essential bodily functions for some time, while losing daily a not inconsiderable amount of protein. To cite a single striking example, Rubner observed in a fasting rabbit up to the time of death, on the nineteenth day, a loss of 45.2 per cent of the computed nitrogen of the body.[c] While this is an extreme case, nevertheless it is evident that there must be a relatively large loss of body protein in those more moderate cases in which the deprivation of protein is not continued so long as to cause death. Furthermore, the losses occurring in these latter cases may be made good by subsequent feeding and the animal restored to its original state. Striking examples of the same fact are familiar in the human subject in the emaciation due to long illness and the restoration of the body during convalescence. Pugliere[d] has shown that a similar storage of protein takes place rather rapidly in the liver when a previously fasted animal receives feed again.

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[a] Neue Beiträge, etc., p. 446.

[b] U. S. Department of Agriculture, Bureau of Animal Industry, Bulletins 51 and 74.

[c] E. Voit. Zeitschrift für Biologie, bd. 41, p. 139.

[d] Jahresbericht über die Fortschritte der Tierchemie, bd. 34, p. 529.

In brief, it is evident that the protein content of the body of the mature animal may fluctuate within rather wide limits without necessarily causing any serious or permanent derangement of its functions. We can hardly regard such a fluctuation as consisting to any large extent of an actual destruction and rebuilding of the cells of muscular and other tissue. It seems more reasonable to suppose that it is effected chiefly by changes in the amount of cell contents—an alternate atrophy and hypertrophy of the cells under the influence of the changing protein supply. In other words, as regards its stock of protein, the organism may exist and function at a higher or lower level—a conclusion equivalent to Voit's conception of organized and circulatory protein in a slightly modified form. With carnivora on a largely protein diet, such as was used in Voit's experiments, the adjustment of the body to the protein supply seems to take place rather promptly. In the case of herbivora, however, the adjustment appears to be more gradual, possibly owing to the relatively large supply of nonnitrogenous ingredients in their food, and apparently some gain of protein may continue for a considerable time, although when expressed as a percentage of either the total feed protein, or especially of the body protein, the gain is relatively small.

The following table contains a summary of the principal results on record regarding the gain of protein by mature animals, omitting several negative results. The figures are exclusive of wool or feathers.

Gain of protein by mature animals.

Experimenter and publication.	Animal.	Age of animal.	Character of experiment.	Average live weight.	Gain of protein expressed as percentage of total body protein.	Daily gain of nitrogen[a] per head.	Daily gain of protein per head.	Daily gain of protein per 1,000 kilograms live weight.
				Kilograms.	*Per cent.*	*Grams.*	*Grams.*	*Kilograms.*
Henneberg, Fleischer, and Müller (Jahresbericht der Agriculturchemie, jahrg. 16-17, bd. 2, p. 145).	Sheep	4 years	Metabolism	34.2	0.038	0.32	1.92	0.056
					.123	1.04	6.24	.182
					.343	2.89	17.34	.507
Henneberg, Kern, and Wattenberg (Journal für Landwirtschaft, bd. 26, p. 549).	do	2¾ years	Slaughter	46.6	.089	5.53	33.18	.712
				50.0	.041	2.57	15.42	.308
Soxhlet (Biederman's Central-Blatt für Agrikulturchemie, etc., jahrg. 10, p. 674).	Swine	17½ months	do	119	.608	11.83	70.98	.596
				116	.291	5.49	32.94	.283
B. Schulze (Landwirtschaftliche Jahrbücher, jahrg. 11, p. 57).	Geese	9 to 10 months	do	3.68	.359	10.54	63.24	17.182
				3.84	.361	8.13	48.78	12.703
				3.83	.241	5.30	31.80	8.302
				3.83	.471	14.59	87.54	22.856
				3.81	.067	3.74	22.44	5.889
Meissl (Zeitschrift für Biologie, bd. 22, p. 63)	Swine	14 months	Metabolism	140	.176	6.08	36.48	.261
		15 months		70	.453	7.82	46.92	.670
		14 months		125	.177	5.46	32.76	.262
		18 months		104	.282	7.22	43.32	.416
Henneberg and Pfeiffer (Journal für Landwirtschaft, bd. 38, p. 215).	Sheep I	3½ years	do	44	.039	0.42	2.52	.057
					.299	3.25	19.50	.443
					.077	0.08	.16	.004
	Sheep II	3½ years	do	43	.193	2.03	12.18	.283
					.343	3.62	21.72	.505
					.096	1.01	6.06	.141
Pfeiffer and Kalb (Landwirtschaftliche Jahrbücher, jahrg. 21, p. 175).	Sheep I	(b)	do	42	.121	1.29	7.74	.184
		(b)			.067	0.71	4.26	.101
		(b)			.068	0.73	4.38	.104
	Sheep II	(b)	do	35	.134	1.15	6.90	.197
		(b)			.086	0.74	4.44	.127
		(b)			.141	1.21	7.26	.207
	Sheep III	(b)	do	42	.203	2.06	12.36	.294
	Sheep IV	(b)	do	35	.197	1.71	10.26	.292
		(b)			.027	0.23	1.38	.039

[a] Not including wool in case of sheep.

[b] Not stated.

The recent Moeckern investigations show even smaller gains of protein by mature fattening cattle in proportion to live weight. Grouping the large number of these experiments according to the amount of digestible protein fed, we obtain the following averages:

Gain of protein by mature cattle.

No. of experiments.	Average live weight.	Daily average digestible protein fed per head.	Daily average gain of nitrogen per head.	Daily gain of protein per 1,000 kilograms live weight.	Daily gain of protein in percentage of total body protein.[a]
	Kilograms.	*Grams.*	*Grams.*	*Kilograms.*	
7	656	343	9.53	0.087	0.0550
14	651	485	8.93	.082	.0518
18	667	713	14.57	.131	.0829
11	671	894	17.22	.154	.0974
10	691	1,497	18.08	.157	.0993

[a] Assumed to be 15.8 per cent of live weight.

Rate of growth of lean meat.—Most of the experiments just referred to relate to the growth of the total protein tissue of the body, including, besides the edible portion, the protein of the skin, hair, hoofs, horns, and other epidermal tissue, of the internal organs, and of the skeleton. While we may fairly assume that the increase of edible meat will be in a general way proportional to the increase of total protein, it is equally clear that there may be considerable departures from the average. It is important, therefore, to inquire into the rate of increase of the edible portion of the carcass. Unfortunately, however, the data upon this point are scanty, owing to the laborious and expensive nature of the experiments. About the only results available are those of Henneberg et al. on lambs and on mature sheep, and those of Jordan on steers—that is, these are the only ones which permit of a comparison of the rate of growth of similar animals in successive periods.

Henneberg's experiments on lambs[a] have been outlined on a previous page. The following table shows the gains of fat-free lean meat in the same experiments, as compared with the gains of total protein, the latter being computed from the increase of the "fat-free body" by multiplication by 0.205. The meat refers only to the meat of the "butcher's pieces," freed from sinews and coarser connective tissue by passage through a meat grinder.

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[a] Journal für Landwirtschaft, bd. 28, p. 289.

Gain of fat-free lean meat and total protein by lambs.

Lot.	Period.	Length of period.	Character of ration.	Average age of animals.	Gain per week and head	
					Fresh, fat-free meat.	Total dry protein (estimated).
		Days.		*Days.*	*Kilograms.*	*Kilograms*
1	I and II	203	Growing	290	0.114	0.056
	III and IV	259	do	521	.053	.031
	V	175	Fattening	745	.042	.029
2	I and II	189	do	290	.130	.077
	III	147	do	458	.040	.026

In this case the gain of fat-free lean meat was, in general, parallel to the gain of total protein (or more strictly to the gain of the fat-free body), diminishing with advancing maturity. Apparently, however, the rate of gain of total protein increased slightly as compared with that of edible meat, as shown by the following table of the relative gains in the several periods, that on Periods I and II being taken as unity:

Relative gains of fat-free lean meat and total protein by lambs.

Lot.	Period.	Fat-free lean meat.	Total protein.
		Kilograms.	*Kilograms.*
1	I and II	1.000	1.000
	III and IV	.465	.554
	V	.368	.518
2	I and II	1.000	1.000
	III	.308	.338

The experiments with mature sheep[a] were conducted upon substantially the same plan as those with lambs, with the following results:

Gain of fat-free meat and total protein by mature sheep.

No. of animal.	Condition at close of period.	Length of period.	Gain per week and head.		
			Fresh, fat-free meat.	Dry, fat-free meat.	Total dry protein (estimated).
			Kilograms.	*Grams.*	*Kilograms.*
6	Fat	70 days	−0.015	1.99	+0.039
8	Very fat	203 days	− .008	3.99	+ .018
8	do	Last 133 days	+ .020	5.04	+ .007

In no case was there any material gain in the weight of fresh, fat-free meat, and while there was a slight gain of dry matter in the fat-free meat, it was, in the earlier stages of fattening, much less than the computed gain of total protein. The greater increase during the later stages of the experiment was due chiefly to an increase in the nitrogenous extractives of the meat, particularly of the soluble protein, rather than of its insoluble protein, about two-thirds of the small computed gain of protein being in the form first named.

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[a] Journal für Landwirtschaft, bd. 26, p. 549.

Jordan's experiments include a comparison of the weights and chemical composition of two pairs of animals at the end of twenty-seven months' and seventeen months' feeding, respectively. The protein of the lean meat, after mechanical separation from the fat tissue, and the total body protein were as follows:

Gain of protein of lean meat and of total protein by steers.

No. of animal.	Average age.	Protein of lean meat.	Total protein of body.
		Pounds.	*Pounds.*
2	32 months	42.13	167.94
1	22 months	[a] 37.96	136.30
	Gain in 10 months	4.17	31.64
	Gain per day	.0128	.0971
3	32 months	43.24	161.38
4	22 months	[a] 35.08	126.30
	Gain in 10 months	8.16	35.08
	Gain per day	.0261	.1123

[a] Nos. 1 and 4 were somewhat lighter animals than Nos. 2 and 3. The protein content has been computed to the live weight of the heavier animal in each case.

It would appear, so far as conclusions can be safely drawn from these few results, that while the gain of lean meat, like that of total protein, diminishes with age, the diminution is more rapid in the former case than in the latter. At all ages the storage of total protein (or, more exactly, the increase in the fat-free body) considerably exceeds the gain of lean meat proper, and with increasing maturity this difference seems to become relatively greater.

INFLUENCE OF PROTEIN SUPPLY ON RATE OF GROWTH.

The essential feature of growth being the increase in protein tissue, the question is at once suggested whether the rate of growth may be stimulated or the reverse by an abundant or limited protein supply in the feed.

As regards the latter branch of the question, it is self-evident that if the feed contains less digestible protein than corresponds to the normal rate of growth, the latter must be diminished by simple lack of material. A considerable number of feeding experiments have been made with growing animals, notably with swine, in which the character of the carcasses produced on rations poor and rich in protein (the so-called "feeding for fat and for lean") has been compared. In few or none of these experiments has the actual increase of proteid tissue been determined, but in a majority of them there has appeared to the eye a deficiency in the development of the muscular system on the protein-poor rations, accompanied usually by a relative excess of fat. The results of Fuller[a] upon young pigs appear to show in a very striking manner the effect of a deficient protein supply in limiting growth, but the presence of intestinal worms in large numbers in the corn-fed lot detracts from the force of the conclusions. Moreover, there are not lacking indications that in some of the other experiments the deficiency of lean meat and excess of fat were more apparent than real, and that the distribution of the fat in the carcasses rather than its amount was the controlling factor in their commercial valuation.

When we ask, however, whether the rate of growth can be stimulated by an abundant protein supply, the answer is not so easy. Evidently we can not readily compare results on the same animal at different ages on account of the marked influence of the latter factor on the rate of gain, while comparisons between two animals or lots are liable to be disturbed by the factor of individuality. Moreover, aside from these difficulties, there is no obvious way of determining what is to be regarded as a normal rate of growth or whether the protein supply of the check animal or lot has been sufficient to enable it to reach this normal rate. A review of such of the experiments cited in connection with the discussion of the influence of age on protein metabolism as afford data bearing on this point seems to indicate that there may be some stimulative effect of this sort. In most cases the greater absolute and relative gain of protein is found in those animals receiving the greater amount of protein in their feed. The most marked instances are Soxhlet's results with calves, Henneberg's with lambs, and Jordan's with steers. In all these cases the more liberal protein supply seems to have hastened growth in the earlier periods, while in the later periods the growth was less than on the lower protein supply. This is true also of the averages of the Moeckern experiments on mature animals, cited on a previous page.

The effect, however, was in nearly all cases relatively small. The fact, pointed out in the same discussion, that an abundant protein supply may, for a time at least, cause more or less storage of protein in mature animals points in the same direction. Such storage was there interpreted as probably consisting chiefly in a hypertrophy of the cells. There seems no obvious reason why the same effect may not be produced in growing animals, and it is easy to imagine that a surplus of protein in the contents of the cell may tend to stimulate the growth of the bioplasm itself.

Abderhalden[b] has shown that the rate of growth of different species of animals is quite closely parallel to the percentage of protein in the milk, but, as Minot[c] points out, this is in all probability the result of an adaptation of the composition of the milk to the demands of the young animal, the rate of growth being cause and not consequence.

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[a] Wisconsin Experiment Station, Report 21 (1903–4), p. 25.

[b] Zeitschrift Physiologische Chemie, bd. 26, p. 497.

[c] Loc. cit.

It would seem, then, that we may regard each animal as endowed with a certain normal rate of growth. A liberal supply of protein may perhaps stimulate this rate of growth somewhat, resulting, for a time at least, in a greater storage of protein, and perhaps a tendency to earlier maturity, although it seems unlikely that the effect can be great. On the other hand, it appears reasonably certain that the rate of growth may be materially reduced by a deficiency of protein in the ration, even when this deficiency is not so great as to result in any obvious disturbance of the bodily functions or even a greatly diminished gain in live weight.

PROTEIN REQUIREMENTS.

In the foregoing paragraphs have been outlined the general features of the production of protein tissues in the growing animal. We next inquire what quantities of protein are required in the feed to insure the "normal" rate of growth.

Requirements for growth.—Obviously, the feed must contain at least an amount of protein equal to that stored as growth. This amount per 1,000 pounds live weight can, as we have seen, be roughly and approximately expressed by the equation

$$g = \frac{135}{a + 20}.$$

While the rate of growth doubtless shows considerable variation in different individuals, the diagram already presented seems to justify us in regarding the figures thus obtained as representing fairly well the "normal" rate of growth, for which proteid material must be provided.

Requirements for maintenance.—In addition to the protein required for growth, the feed must supply sufficient protein to make good the katabolism of this material which is constantly going on in living tissue; that is, it must contain the minimum of protein required for maintenance. For mature cattle this appears to be from 0.4 to 0.6 pound per day per 1,000 pounds live weight, or perhaps 0.5 pound as a general average. For mature sheep the current feeding standards call for 1.2 to 1.4 pounds per 1,000 pounds live weight, but there is little doubt that, like the current standard for cattle, this is too high. The average growth of wool per day would scarcely amount to more than 0.15 pound of protein per 1,000 pounds live weight, and even if we assume the protein metabolism of sheep to be more active than that of cattle it would seem that 0.75 to 0.80 pound per day would be an ample allowance for maintenance. For swine no data seem to be available.

The above statements refer to the maintenance requirements of mature animals. Whether the same figures apply substantially to growing animals, or whether their necessary protein metabolism, like their total metabolism, is more active, relatively to their weight, is largely a matter of conjecture. Assuming, for the time being, that the former is the case, and letting *m* equal the daily protein requirement for maintenance and *p* equal total protein requirement, the formula above becomes

$$p = \frac{135}{a + 20} + m.$$

Is protein required for other purposes?—If we computed the average protein requirements at different ages by means of the foregoing formula, letting *m* equal 0.50, we obtain results differing most strikingly from accepted figures, as the following comparison of the computed results with the Wolff-Lehmann and with Kellner's standards for beef cattle makes evident.

Protein requirement of cattle per 1,000 pounds live weight.

Age.	Computed from formula.	Wolff-Lehmann standards.	Kellner's standards.	
			Milking and working animals.	Fattening animals.
Months.	*Pounds.*	*Pounds.*	*Pounds*	*Pounds.*
2 to 3....	1.92	4.3	3.4	4.5
3 to 6....	1.37	3.5	2.8	3.5
6 to 12...	.97	2.5	2.3	2.8
12 to 18..	.79	2.0	1.8	2.2
18 to 24..	.71	1.8	1.3	1.5

The foregoing comparison, however, simply shows that the computed amounts of protein are only about one-half those thought to be advisable in practice, without in itself affording any proof that the latter estimates are too high. As a matter of fact, while more recent investigation has shown that the Wolff-Lehmann standards for protein are unnecessarily high for mature or nearly mature animals, the same thing does not seem to be true of the standards for growth, as appears from the comparisons summarized on page 71.

It is quite conceivable and indeed probable that the growing body has other demands for protein than those just indicated. Thus, there may very well be a considerable necessary margin of waste in the conversion of feed protein into body protein. So, too, the digestion of the relatively large amount of feed constituting a growing or fattening ration, as compared with a maintenance ration, would apparently call for a larger production of digestive enzymes, which are doubtless protein in nature. The extent of this demand, however, and the degree to which the secreted enzymes are reabsorbed are largely matters of speculation. It seems possible that part of the "depression" of digestion with rations poor in protein may arise from deficient digestive ferments. At any rate, the inferior digestibility of such rations is a factor in the practical economy of feeding.

Finally, the processes both of growth proper and of fattening involve a large amount of metabolic activity in the body. But a relatively small portion of the metabolizable energy of the feed is finally stored up in the body, the larger share of the matter bearing it being katabolized, and its energy finally liberated as heat. It seems quite in accord with what we know of the katabolic activity of the cells and tissues of the body to suppose that this increased activity on their part may involve an increased breaking down of their protein as well as of their nonnitrogenous constituents, and so give rise to a corresponding demand for protein in the feed.

Unfortunately, few or no experiments directed specifically to the determination of the necessary minimum of protein for animals of different species and of different ages are on record, so that for practical purposes we are compelled to glean such information as we can on this point from practical feeding experiments in which the protein supply has varied. These data will be considered later in another connection.

INDIVIDUAL DIFFERENCES.

It is a matter of common experience that there exist marked differences between individuals of the same species both as to the weight finally attained by the mature animal and as to the rate of growth at the same age.

We should naturally be inclined to interpret this fact as indicating corresponding individual differences in the rate of gain of proteid tissue, but the writer is not aware of any recorded experiments bearing specifically on this point. It is true that the quality of early maturity is popularly attributed to the meat breeds, but as regards cattle at least Henry[a] has shown that the data at hand fail to prove that the beef breeds as such show a greater rate of gain in live weight or a greater weight at maturity than do the dairy breeds. If we are correct in ascribing the individual differences noted above to variations in the rate of growth of protein tissue, it would seem to open up a field for investigation of the highest interest to the breeder and feeder.

LAWS OF FATTENING.

As already pointed out, fattening is, strictly speaking, as the word implies, the accumulation of adipose tissue in the body, resulting in or at least accompanied by an improvement in the quality of the lean meat. Such a gain of fat by the animal of course implies an excess of feed over the requirements for maintenance and for normal growth of protein tissue, and, conversely, any period of heavy feeding will cause a fattening whether the animal be young or mature.

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[a] Feeds and Feeding, second edition, p. 374.

For our present purpose it will be convenient to use the term fattening more nearly in its commercial sense as denoting heavy feeding, whether of mature or immature animals, for the production of marketable carcasses.

COMPOSITION OF INCREASE.

The amount of protein gained, as has been shown, is largely dependent upon the age and to a less degree upon the individuality of the animal, although probably affected to some extent by the supply of feed protein. The fat formation, on the other hand, is primarily dependent, in a broad general way at least, upon the total feed supply. Accordingly, we should anticipate that the composition of the increase would vary with the age of the animal, consisting more and more largely of fat with increasing maturity.

Proportion of protein and fat.—From this point of view the nature of the increase is best characterized by the ratio of protein to fat—that is, by the composition of the water-free and ash-free gain, leaving for later consideration the actual composition of the total gain in live weight. It seems desirable also to distinguish, so far as possible, between the gain of protein in the form of lean meat or of the soft tissues and that in the form of epidermal tissues (hair, feathers, hoofs, horns, etc.), although as a matter of fact the proportion in the latter is relatively slight except in a few experiments with geese.

The following tabulation contains the results of the experiments accessible to the writer which afford more or less complete data as to the composition of the increase. Those on growing animals are arranged roughly according to age.

Proportion of protein and fat in the gains made by growing and mature animals.

GROWING ANIMALS.

Author.	Nature of experiments.	Designation of animal or period.	Average age.	Composition of dry and ash-free increase.		
				Protein of epidermis.	Remainder of protein.	Fat.
				Per cent.		*P. ct.*
Wilson	Comparative slaughter tests on pigs.	Skim milk	8 days		92.50	7.50
		Lactose	8 days		91.08	8.92
		Dextrose	8 days		91.35	8.65
Soxhlet	Respiration experiments on calves.	B 1	15 days		54.57	45.43
		B 2	21 days		49.90	50.10
		C	8 days		56.42	43.58
Tschirwinsky	Comparative slaughter tests on pigs.	No. 3	114 days	0.10	18.19	81.71
		No. 2	134 days	.16	15.16	84.68
Henneberg, Kern, and Wattenberg.	Comparative slaughter tests on lambs.	Lot 1:				
		Periods I and II	290 days		[a] 21.21	78.79
		Periods III and IV.	521 days		[a] 9.31	90.69
		Period V	745 days		[a] 7.34	92.66
		Lot 2:				
		Periods I and II	290 days		[a] 16.08	83.92
		Period III	458 days		[a] 6.40	93.60
Jordan	Comparative slaughter test on cattle.	Average	840 days		25.06	74.94

Proportion of protein and fat in the gains made by growing and mature animals—Cont'd.

MATURE ANIMALS.

Author.	Nature of experiments.	Designation of animal or period.	Average age.	Composition of dry and ash-free increase.		
				Protein of epidermis.	Remainder of protein.	Fat.
				Per cent.		*P. ct.*
Henneberg, Fleischer, and Müller.	Respiration experiments on sheep.	Period I	4 years		4.26	95.74
Henneberg, Kern, and Wattenberg.	Comparative slaughter tests on sheep.	No. 6	2¾ years		3.84	96.16
		No. 8, total			3.71	96.29
		No. 8, last period			3.26	96.74
Soxhlet	Comparative slaughter tests on swine.	No. 1	16½ months	35.48		64.52
		No. 2		11.26		88.74
B. Schulze	Comparative slaughter tests on geese.	No. 1	9 months	1.69	10.99	87.32
		No. 2		7.53	−1.94	109.47
		No. 3		− .07	8.57	91.50
		No. 4		−1.46	6.33	95.13
		No. 5		−4.71	9.41	85.88
		No. 6		1.89	2.58	95.53
Chaniewski	do	No. 2	(?)	8.39	1.05	90.56
		No. 3	(?)	6.44	−5.30	98.86
Meissl et al.	Respiration experiments on swine.	No. 1	14 months	9.75		90.25
		No. 2	15 months	10.67		89.33
		No. 3	14 months	16.39		83.61
		No. 4	18 months	15.16		84.84
Lawes and Gilbert.	Comparative slaughter tests.	Average for cattle, sheep, and swine.		9.67		90.33

[a] Computed from "fat-free body."

In addition to the above, Kühn's and Kellner's extensive investigations at the Moeckern Experiment Station call for special consideration. These were respiration experiments on mature cattle, the actual experimental periods ranging from two to four weeks, but not usually less than three, the periods not infrequently being separated by transition feedings of two or three weeks.

Out of all the experiments, 60 in number, which show a gain of both protein and fat, only 3 show less than 70 per cent fat in the total gain and only 3 a percentage above 95. Rejecting these 6 and grouping the remainder according to the percentage of fat, we have the following results:

Results of respiration experiments with mature cattle at the Moeckern Experiment Station.

Group No.	Number of experiments.	Digestible protein fed.	Range of percentage of fat in gain.	Composition of dry ash-free gain.		Average total energy of gain.	Metabolizable energy of feed.
				Total protein.	Fat.		
		Grams.		*Per cent.*	*Per cent.*	*Calories.*	*Calories.*
I	5	822	70—74.99	26.25	73.75	3,858	21,519
II	7	829	75—79.99	23.30	76.70	3,771	21,210
III	19	598	80—84.99	17.17	82.83	4,445	21,762
IV	14	1,064	85—89.99	12.55	87.45	6,288	26,483
V	9	644	90—94.99	8.06	91.94	6,185	25,783

The actual gains of protein and fat per day and head were as follows:

Actual gain of protein and fat per day and head.

Group No.	Protein.	Fat.
	Grams.	*Grams.*
I	119.1	334.8
II	90.0	296.3
III	81.6	393.3
IV	87.5	609.5
V	53.3	608.0

It is evident from the foregoing tables that the gain of organic matter by the fattening animal consists chiefly of fat except in the case of the very young animal. In but few cases does the percentage of fat in the organic matter gained fall below 80, and in the majority of cases it ranges between 80 and 90.

Composition of total increase.—From such of the foregoing experiments as admit of it, the composition of the total increase in live weight has been computed, with the following results:

Composition of total increase in live weight in growing and mature animals.

GROWING ANIMALS.

Author.	Designation of animal or period.	Average age.	Composition of increase.				Energy of 1 kilogram of increase.
			Water.	Ash.	Protein.	Fat.	
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Calories.*
Wilson	Skim milk	8 days	80.08	[a] 0.03	18.40	1.49	1,191
	Lactose	8 days	78.91	[a] 1.42	17.92	1.75	1,188
	Dextrose	8 days	79.44	[a] 1.62	17.30	1.64	1,142
Soxhlet	B. 1	15 days	61.28	3.63	19.15	15.94	2,606
	B. 2	21 days	62.13	3.50	17.15	17.22	2,614
	C.	8 days	62.55	3.35	19.24	14.86	2,508
Tschirwinsky	No. 3	114 days	46.51	3.73	9.10	40.66	4,382
	No. 2	134 days	34.23	2.24	9.73	53.80	5,666
Henneberg, Kern, and Wattenberg.	Lot I:						
	Periods I and II	290 days	43.84		[b] 11.31	44.85	4,906
	Periods III and IV	521 days	27.27		[b] 7.03	65.70	6,643
	Period V	745 days	22.18		[b] 5.72	72.10	7,175
	Lot II:						
	Periods I and II	290 days	38.41		[b] 9.91	51.68	5,475
	Period III	458 days	16.03		[b] 4.13	79.84	7,820
Jordan [c]	Average	840 days	39.65	6.18	13.57	40.60	4,630

MATURE ANIMALS.

Author.	Designation of animal or period.	Average age.	Water.	Ash.	Protein.	Fat.	Energy of 1 kilogram of increase.
Henneberg, Kern, and Wattenberg.	No. 6	2¾ years	13.00		[b] 3.35	83.65	8,138
	No. 8 (total)		12.48		[b] 3.23	84.27	8,190
	No. 8 (last period)		11.23		[b] 2.90	85.87	8,323
Soxhlet	No. 1	16½ months	58.96	3.17	13.42	24.45	3,088
	No. 2	16½ months	35.99	3.62	6.80	53.59	5,479
B. Schulze	No. 1	9 months	46.53	1.01	6.65	45.81	4,731
	No. 2		35.00	2.15	−5.96	68.81	6,197
	No. 3		33.12	1.46	5.56	59.86	6,004
	No. 4		23.79	1.62	3.63	70.96	6,249
	No. 5		47.28	0.69	7.35	44.68	4,664
	No. 6		36.65	0.30	2.82	60.23	5.883
Chaniewski	No. 2	(?)	42.92	2.21	5.20	49.67	5.015
	No. 3	(?)	25.37	0.54	0.84	73.25	7,007
Lawes and Gilbert	Average for cattle, sheep, and swine.		23.80	1.10	7.26	67.80	7,055

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[a] By difference.

[b] Computed from "fat-free body."

[c] The figures differ slightly from those computed by the author.

The most obvious showing of this, as of the previous tabulations, is the wide range in the composition of the increase. Even aside from the very young animals, in which the gain consists chiefly of water and protein, we see that the percentage of dry matter in the gain and the proportions of fat, protein, and ash in the latter vary within wide limits. It is very clear that a pound of gain in weight may require a very different food expenditure for its production in different cases, and is an exceedingly variable standard by which to measure the effects of a ration.

Influence of progressive fattening.—The results just cited, in most cases, are either those of an entire fattening period, or else, especially in the case of the respiration experiments (including the Moeckern experiments), those of a short period of feeding with at most only moderately fat animals.

It would appear probable that with the progress of the fattening the proportion of protein stored would tend to decrease, and that the gain would consist to an increasing extent of fat. This supposition is confirmed by the results of Henneberg et al. on lambs and sheep (included in the foregoing tables), but these appear to be the only data bearing on this point. Their results on lambs show a marked diminution in the percentage of water in the gain, a result which corresponds to the general showing of the last table and with the well-known fact that the bodies of young animals contain a higher percentage of water than do those of mature animals. The proportion of protein in the dry matter of the gain decreases notably, while that of fat, of course, increases correspondingly. In the mature sheep there is also a falling off in the percentage of water and protein and an increase in that of fat, in the later stages of fattening, but the differences are relatively small and perhaps within the limits of error of such experiments.

Energy value of increase.—The wide range of composition shown by the gain in live weight has already been commented upon. It is of some interest, however, to reduce these results to a common measure by computing the energy value of the increase. Estimating 5.7 calories per gram of protein and 9.5 calories per gram of fat, the computed energy values per kilogram of gain are as shown in the last column of the preceding table.

INFLUENCE OF FATTENING ON COMPOSITION OF LEAN MEAT.

As has been already pointed out, the accumulation of adipose tissue in the fattening process appears to be of secondary importance, the main object being to improve the quality of the lean meat. It becomes of interest, therefore, to inquire what chemical or other differences exist between the meat of lean and of fat animals. Comparatively few data are available upon this point, but, nevertheless, some interesting indications may be found.

In Henneberg's experiments on sheep,[a] the meat, after trimming off as much fat as practicable, was ground, the coarser connective tissue being removed in the process. This "meat" contained in the water-free substance:

Relative proportion of fat and fat-free meat in the lean meat of sheep.

	Sheep No. 18 (lean).	Sheep No. 6 (fat).	Sheep No. 8 (very fat).
	Per cent.	*Per cent.*	*Per cent.*
Fat	24.87	15.04	16.27
Fat-free meat	75.13	84.96	83.73
Total	100.00	100.00	100.00

The meat of sheep No. 18 was not trimmed and there is no guaranty of uniformity of trimming in the other two cases.

The composition of the fresh fat-free meat of sheep No. 8 and No. 18 was as follows:

Composition of fresh fat-free meat of sheep.

	Sheep No. 18 (lean).	Sheep No. 8 (very fat)
	Per cent.	*Per cent.*
Water	79.41	79.02
Insoluble protein	15.85	15.73
Extractives:		
Protein	1.29	1.93
Nonprotein	2.18	2.17
Ash	1.27	1.15
	4.74	5.25
Total	100.00	100.00

There was evidently an increase in the extractives of the fat-free meat and a corresponding decrease in the percentage of water, while the proportion of insoluble protein (muscular fiber) is practically unchanged. Comparing the absolute amounts contained in the bodies of the two animals, the computed gain during fattening was—

		Grams.
Insoluble protein		38.7
Extractives:		
Protein	82.0	77.0
Nonprotein	4.2	
Ash	−9.2	
Total		115.7

Henneberg's experiments on lambs,[b] computed in the same manner as those upon sheep, give the following as the composition of the trimmed butcher's cuts:

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[a] Journal für Landwirtschaft, bd. 26, pp. 585–611.

[b] Ibid., bd. 28, pp. 359–377.

Relative proportion of fat and fat-free meat in the lean meat of lambs.

	Fat-free meat, fresh.	Fat.
Lot 1:	*Per cent.*	*Per cent.*
Beginning of Period I	88.16	11.84
End of Period II	87.38	12.62
End of Period IV	80.24	19.76
End of Period V	81.28	18.72
Lot 2:		
End of Period II	84.72	15.28
End of Period III	75.53	24.47

If we may assume that the trimming of the meat was uniform, there is shown clearly an increase in the fat content of the meat, both during growth and during the fattening of lot 2, but the fattening period (V) for lot 1 shows no increase over the preceding period.

The composition of the fat-free meat was as follows:

Composition of fat-free meat of lambs.

	Lot 1.				Lot 2.	
	Beginning of Period I.	End of Period II.	End of Period IV.	End of Period V.	End of Period II.	End of Period III.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Insoluble protein	14.89	15.12	15.74	15.90	14.86	15.65
Soluble protein	1.56	1.72	1.63	1.90	2.16	2.16
Nonprotein	1.44	1.74	2.14	2.40	1.66	1.84
Ash	1.10	1.07	1.14	1.20	1.11	1.18
Total dry matter	18.99	19.65	20.65	21.40	19.79	20.83
Water	81.01	80.35	79.35	78.60	80.21	79.17
	100.00	100.00	100.00	100.00	100.00	100.00
Total extractives	4.10	4.53	4.91	5.50	4.93	5.18

There is evident in both lots an increase in the percentage of dry matter in the fat-free meat, but there seems to be no marked difference in this respect between the effects of the growing rations of lot 1 in the first four periods and those of the fattening ration of lot 2 and of lot 1 in Period V. The increase in the percentage of extractives was relatively greater than in that of the insoluble protein, as the following computation of the composition of the dry matter shows:

Composition of dry matter of fat-free meat of lambs.

In fat-free dry matter.	Lot 1.				Lot 2.	
	Beginning of Period I.	End of Period II.	End of Period IV.	End of Period V.	End of Period II.	End of Period III.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Insoluble protein	78.42	76.95	76.23	74.30	75.10	75.13
Soluble protein	8.21	8.75	7.89	8.88	10.90	10.37
Nonprotein	7.58	8.85	10.36	11.21	8.39	8.83
Ash	5.79	5.45	5.52	5.61	5.61	5.67
	100.00	100.00	100.00	100.00	100.00	100.00
Extractives	21.58	23.05	23.77	25.70	24.90	24.87

The fattening appears to have caused some increase in the total extractives as compared with the growing rations. The difference is due to a somewhat marked increase in the soluble protein in lot 2, while the nonprotein shows a relative decrease. The final fattening of lot 1 also caused an increase in the extractives rather than in the insoluble protein, this increase, however, being chiefly in the nonprotein.

In Jordan's experiments,[a] we have data as to the composition of the trimmed lean meat of the carcasses of two steers about 22 months old and of two about 30 months old, as follows:

Composition of fresh lean meat of steers.

Animals.	Water.	Protein.	Fat.	Ash.
Steers 22 months old:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
No. 1	70.95	19.54	8.58	0.93
No. 4	69.07	20.11	9.83	.99
Average	70.01	19.83	9.20	.96
Steers 32 months old:				
No. 2	69.80	18.74	10.52	.94
No. 3	70.37	19.86	8.81	.96
Average	70.09	19.30	9.66	.95

These figures show very little difference in the composition of the meat of the two sets of animals, but it is to be noted that the rations fed were growing rather than fattening rations. The comparison on page 17 shows that even during the last ten months considerable growth took place.

Leyder and Pyro[b] report the following figures for the composition of lean meat from different cuts of beef. The ash is assumed as 1 per cent in every case, and the remainder of the fat-free dry matter is regarded as protein.

Composition of lean meat from various cuts of beef.

	Lean cow.	Fat ox.	Very fat cow.
Neck:	*Per cent.*	*Per cent.*	*Per cent.*
Water	76.5	78.0	76.2
Ash	1.0	1.0	1.0
Fat	1.3	1.0	2.8
Protein	21.2	20.0	20.0
	100.0	100.0	100.0
Leg:			
Water	77.1	75.0	73.3
Ash	1.0	1.0	1.0
Fat	0.9	4.0	5.8
Protein	21.0	20.0	19.9
	100.0	100.0	100.0

[a] Maine Experiment Station, Report for 1905, vol. 2, pp. 66–69.

[b] Biedermann's Central-Blatt für Agrikulturchemie, etc., bd. 10, p. 43.

Composition of lean meat from various cuts of beef—Continued.

	Lean cow.	Fat ox.	Very fat cow.
Flank:	*Per cent.*	*Per cent.*	*Per cent.*
Water	77.5	76.8	67.8
Ash	1.0	1.0	1.0
Fat	0.8	4.3	8.8
Protein	20.7	17.9	22.4
	100.0	100.0	100.0
Tenderloin:			
Water	76.6	70.6	67.3
Ash	1.0	1.0	1.0
Fat	2.6	8.0	12.9
Protein	19.8	20.4	18.8
	100.0	100.0	100.0

They cite also the following comparison by Siegert[a] of the meat of lean and fat oxen:

Composition of meat from lean and fat oxen.

	Lean oxen.	Fat oxen.
Neck:	*Per cent.*	*Per cent.*
Water	77.5	73.5
Ash	1.2	1.2
Fat	.9	5.8
Protein	20.4	19.5
	100.0	100.0
Rib:		
Water	76.5	50.5
Ash	1.2	1.0
Fat	1.3	34.0
Protein	21.0	14.5
	100.0	100.0
Tenderloin:		
Water	77.4	63.4
Ash	1.2	1.1
Fat	1.1	16.7
Protein	20.3	18.8
	100.0	100.0

No statement is made in the abstracts above quoted regarding the preparation of the meat for analysis. The rather high percentages of fat found by Siegert suggest that his samples were of commercial "meat" rather than of lean meat proper.

Moosbruch, Meissl, and Strohmer[b] report analyses of the serratus anterior muscle from 12 fat cattle of various breeds, but give no comparison with unfattened animals. Ten of the cattle were prize animals. Their ages ranged from 25 to 84 months, and their weights from 597 to 960 kilograms. The percentage of dry matter in the meat varied from 25.01 to 40.85 (or, excluding the highest, to 32.90), and the fat from 3,35 to 18.07 (or, excluding the highest, to 12.99).

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[a] Reported also in Biedermann's Central-Blatt für Agrikulturchemie, etc., bd. 13, p. 573.

[b] Biedermann's Central-Blatt für Agrikulturchemie, etc., bd. 13, pp. 531–532.

Petersen[a] found in the lean meat of different cuts of four fat oxen percentages of fat ranging from 1.38 to 6.44, the corresponding percentages of dry matter being 23.32 and 27.05.

Beythien[b] also reports analyses of the lean meat, evidently carefully separated from the fat tissue, of different cuts of beef, pork, and mutton as sold in the Dresden market. The range in the percentage of dry matter and of fat was as follows:

Range of percentage of dry matter and fat in lean of beef, pork, and mutton.

	Dry matter.	Fat.
	Per cent.	*Per cent.*
Beef	26.02–29.57	4.64– 9.54
Pork	25.70–35.07	3.38–14.37
Mutton	25.98–27.30	5.75– 6.14

He also gives valuable data as to the proportion of lean meat, fat tissue, and bones in the cuts investigated.

Pfeiffer[c] in the course of an investigation on the distribution of fat in the body, found the following percentages of fat in the muscles of the animals named:

Percentage of fat found in the muscles of dog, rabbit, and hen.

Animal.	In fresh substance.	In dry matter.
Dog:	*Per cent.*	*Per cent.*
Fat	{10.93 {11.03	34.42 35.24
Lean	2.50	9.24
Rabbit:		
Fat	4.41	15.83
Lean	3.52	13.21
Hen:		
Fat	{4.99 {3.92	18.88 14.47
Lean	3.97	14.39

While the foregoing data are not in all respects conclusive, it is plain that to some extent in growth, but especially in fattening, there is a deposition of fat in the lean meat. It is possible that a small proportion of this may be formed in the muscular fibers themselves, but by far the larger part consists of a growth of adipose tissue between the muscle bundles, constituting, when marked, the so-called "marbling" of the meat, which adds to its tenderness and perhaps to its flavor and digestibility when cooked, and increases its nutritive value. It seems probable also that there is some increase in the soluble protein and in the extractives of the muscle, resulting in a further betterment of the quality of the meat.

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[a] Ibid., bd. 16, p. 204.

[b] Ibid., bd. 30, p. 683.

[c] Zeitschrift für Biologie, bd. 23, p. 340.

NATURE OF MEAT PRODUCTION.

The facts presented in the foregoing paragraphs enable us to formulate in somewhat more precise form the statements made at the outset regarding the nature of meat production. As there pointed out, it consists of two more or less distinct processes, viz, growth and fattening. The first of these consists essentially in an increase of the protein tissues of the body. It is relatively most active in the young animal, its rate diminishing at first rapidly and then more slowly, being apparently represented by a curve asymptotic to the zero line. The initial rate of growth and the rapidity with which it diminishes are essentially determined by the individuality of the animal, and are only to a slight degree subject to modification by the food supply, except in the negative sense that a deficient protein supply may of course limit growth for lack of material, while the same appears to be true of the ash supply. On the other hand, while there are some indications that an abundant protein supply may stimulate slightly the process of growth and lead to its earlier completion, the effect seems to be at best slight, and it remains true that the production of protein tissue is substantially a function of the animal and not of the food, and that improvement in this respect is a problem for the breeder rather than for the feeder.

Fattening, on the contrary, is a process which, in a given animal at least, is largely under the control of the feeder. Substantially, it is a function of the quantity of feed consumed by the animal in excess of the requirements for maintenance and growth, and there is lacking any definite proof that the actual storage of energy in the form of gain for a given amount of excess food is seriously affected either by the age or the individuality of the animal. Fattening, therefore, may take place at any age, although of course the greater demand for material for growth in the young animal tends to reduce the proportion of the food available for fattening.

The prime object of fattening is an improvement in the quality of the meat by the deposition of fat between the fibers of the meat, and to some extent by increasing the extractives of the meat itself. The large deposits of fat about the internal organs and under the skin are incidental to this and are to a certain extent a waste. The subcutaneous fat affords a convenient index to the quality of the meat, and of course the adipose tissue of the carcass is of some value, but it largely represents the price paid for the improved quality of the meat proper. It is not impossible that the traditions of the market may cause the process of fattening to be pushed beyond what is necessary.

CHOICE OF ANIMALS FOR MEAT PRODUCTION.

CONFORMATION.

It is a well-recognized fact that the conformation of a meat animal is a very important factor in determining his selling price, especially in the case of cattle. Thus Kennedy [a] reports the following selling prices in the Chicago market of fat steers of beef and dairy types per pound live weight:

	Cents.
2 Hereford	5.00
2 Angus	4.75
2 Holstein	3.85
2 Jersey	3.65

Similarly Mumford [b] found that feeders of high grade, as compared with those of inferior grades, graded distinctly higher when fattened, and brought correspondingly better prices.

So far as these differences in type and conformation affect the value of the finished product, they concern primarily the student of breeding rather than of feeding. Since, however, the question of the influence of breed and individuality upon the feeding capacity of animals is one of great importance, and one upon which more or less misconception exists, it seems desirable to clear the ground by pointing out here some of the chief reasons for the superiority of the meat breeds aside from any differences in feeding capacity. In doing so it will be convenient to use beef cattle for purposes of illustration, since the question has been more especially studied on these animals.

PERCENTAGE OF DRESSED WEIGHT.

The market buys on the basis of live weight, and can therefore afford to pay more for the animal containing the larger proportion of dressed carcass and the smaller proportion of relatively valueless offal. In this respect the improved meat breeds have a distinct advantage. Henry [c] gives the following summary of tests at American experiment stations bearing on this point:

Comparison of percentages of dressed weight of various breeds of cattle.

Breed.	Number of animals.	Number of stations.	Limits of dressed weight.	Average dressed weight.
			Per cent.	*Per cent.*
Hereford	11	4	63.0–68.0	65.0
Red Polled	2	1	63.8–66.5	65.2
Aberdeen-Angus	16	4	63.2–69.0	64.8
Swiss	2	1	....	64.8
Shorthorn	26	5	62.1–68.0	64.4
Galloway	6	3	62.0–66.7	63.9
Devon	7	3	62.5–65.8	63.6
Ayrshire	1	1	....	63.3
Sussex	1	1	....	63.0
Holstein	6	3	60.6–64.4	62.6
Jersey	3	2	58.7–63.9	60.5
Native	9	3	57.9–61.5	60.2

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[a] Iowa Experiment Station, Bulletin 81.

[b] Illinois Experiment Station, Bulletin 90.

[c] Feeds and Feeding, second edition, p. 375.

The same fact is reflected in the results of Mumford's experiments just referred to. The higher grades of feeders, containing the larger infusion of beef blood, dressed a higher percentage than the inferior grades. The results were as follows:

Comparison of the dressed weight of various grades of feeder cattle.

Grade.	Dressed weight.
	Per cent.
Fancy	61.62
Choice	61.52
Good	60.74
Medium	59.70
Common	59.88
Inferior	59.36

DISTRIBUTION OF FAT IN CARCASS.

As Henry [a] has pointed out, an important difference seems to exist between the dairy and beef types of cattle in this respect. He cites a number of results showing a tendency on the part of the former to the deposition of larger amounts of fat, relatively to the dressed weight, about the internal organs. That individuality may play an important part in the matter, however, is indicated by the results of later experiments by Kennedy,[b] in which two Holstein steers showed a lower percentage of internal fat (loose tallow) than either Herefords or Angus. There is no definite proof in these trials other than the better "marbling" of the meat that the beef breeds deposited more fat in the latter.

That the distribution of the fat in the carcass has much to do with the market estimate of its value is strikingly shown by experiments by Curtiss and Craig [c] upon the influence of a wide versus a narrow nutritive ratio on the growth and composition of swine. The carcasses of the lot receiving the wide ratio were regarded by Swift & Co. as too fat, yet analyses of them made by Wiley [d] failed to show any marked difference as regards the total percentages of fat and protein.

PROPORTION OF HIGH-PRICED CUTS.

It is a familiar fact, yet one the importance of which the inexperienced feeder often fails to appreciate, that different portions of the carcass show differences in composition, palatability, and nutritive value, and differ greatly in market price. The high-priced cuts are found on the back and loins, and consequently the steer which shows the best development in these regions is the more valuable animal for both the producer and the butcher, a pound of gain in these cuts being worth in the market four or five times as much as the same gain in the cheaper cuts. The same principle applies of course to other species of animals.

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[a] Ibid., p. 376.

[b] Iowa Experiment Station, Bulletin 91.

[c] Iowa Experiment Station, Bulletin 48, pp. 373–451.

[d] U. S. Department of Agriculture, Division of Chemistry, Bulletin 53.

If, therefore, there exists marked differences in the development of those parts yielding the higher-priced cuts between different breeds or individuals, it is clear that in the selection of animals for meat production this is a point of prime importance. So far as data on this point are available, however, they do not seem to indicate that the differences between breeds are as great in this respect as is ordinarily assumed to be the case. This is illustrated by the results of an experiment by Kennedy,[a] in which steers of the beef and dairy types were compared. The following table shows the percentage of rib and loin beef (the two most valuable cuts) found in each carcass, the estimated market value per pound, and the actual selling price for each animal:

Percentage of ribs and loin in carcasses of beef and dairy breeds of cattle.

	Ribs and loin.		Estimated value per pound.		Selling price per pound live weight.
			Ribs.	Loin.	
	Per cent.		*Cents.*	*Cents.*	*Cents.*
Hereford	27.22	26.48	12.5	15.0	5.00
Do	25.74		12.0	15.0	
Angus	27.65	27.18	12.5	15.0	4.75
Do	26.70		12.0	14.5	
Holstein	25.69	25.94	11.0	14.0	3.85
Do	26.18		10.0	12.0	
Jersey	26.97	25.84	10.0	12.0	3.65
Do	24.71		10.0	12.0	

While there is a slight advantage on the side of the beef breeds, it is relatively small, averaging 3.6 per cent of the figure for the dairy breeds, while the difference in price is 30 per cent.

Earlier experiments by Georgeson[b] and by Wilson and Curtiss[c] gave the following percentages of the same two cuts, showing no very marked advantage on the side of the beef breeds:

Percentage of ribs and loin in carcasses of beef and dairy breeds of cattle.

Authority.	Hereford and Angus.	Shorthorn.	Holstein and Jersey.	Native.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Georgeson		26.2		27.1
Wilson and Curtiss	28.2	27.0	27.1	
Average		26.6		

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[a] Iowa Experiment Station, Bulletin 81.

[b] Kansas Experiment Station, Bulletin 51

[c] Iowa Experiment Station, Bulletin 20.

SIZE AND QUALITY OF CUTS.

The experiments by Kennedy just cited, while not sustaining the claim that the beef breeds yield a much larger proportion of valuable cuts than do the dairy breeds, nevertheless indicate clearly the chief reason for the higher prices paid for the former, viz, that the cuts from the beef animals were esteemed to be of a higher quality and would bring more on the market. An important factor in this case was the size of the cuts. The average dressed weights of these steers were:

	Pounds.
Hereford	1,014
Angus	1,118
Holstein	847
Jersey	865

Size, thickness, and appearance are important factors in the selling price of meat. Furthermore, it is not unlikely that the "marbling"—that is, the deposition of the fat among the fibers of the lean meat—was deficient in the dairy breeds.

Finally, the fineness of fiber, tenderness, juiciness, and flavor of the meat itself all go to make up "that indefinable something described by the word 'quality,'" and which is so large a factor in determining price.

It is possible that prejudice plays some part in the relatively low price paid for animals not conforming to the meat type, but it seems unlikely that this is a large element. For the profitable production of meat the prime element is the development and fixing of breeds and strains which may be counted on to have the desired conformation and size when mature, and this is equally important whether the finishing process is carried out by the breeder or by another.

The prominence of the beef industry in the United States has caused conformation to be especially emphasized in the case of cattle, but what has been said applies equally to other species. As an illustration may be mentioned the results with Tamworth hogs at the Iowa Experiment Station[a] and experiments with the "razorback" hog by the Wisconsin station.

BREED AND INDIVIDUALITY.

While this topic is one which concerns primarily the student of breeding, it is nevertheless too important in its relation to feeding to be omitted from a discussion of that subject, especially since there appears to be considerable uncertainty and confusion of thought regarding it. While we can not expect to clear up all difficulties, we may at least hope to discover the directions in which investigation is needed.

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[a] Bulletin 48.

EARLY MATURITY.

Much stress has been laid, and doubtless rightfully, upon the importance of early maturity in meat animals, yet it is by no means clear that the word maturity has always represented the same idea. Strictly speaking, a mature animal is one which has completed its growth—that is, one in which the increase of protein tissue has reached its natural limit. In this sense, that one of two animals which reaches this natural limit first is the earlier maturing. With animals which reach substantially the same limit of size, this conception of early maturity is, of course, synonymous with a greater absolute rate of protein growth, while, if we express the latter relatively to the weight of the animal, as in previous pages, the same thing is true regardless of size.

In discussing the rate of growth, attention has already been called to the possibility of individual and breed differences in this respect. Since the main object in feeding for meat is the production of protein tissue, it is obvious that an animal which inherits a strong initial impulse to growth in this sense will be the more desirable animal, because the greater initial impulse to growth will shorten the time required for the production of a given weight of lean meat. By thus shortening the feeding period required to reach the desired weight or condition we diminish the expenditure for the simple maintenance of the animal, as well as the expense of care, etc., and the interest on the investment.

Early maturity in this sense would be nearly synonymous with a more rapid gain in weight, since the increase of the growing animal consists largely of protein tissue. As has already been mentioned (p. 29) we have no clear indication of a superiority of the meat breeds in this respect. On the other hand, there would seem to be little doubt of the existence of individual differences between animals, and it may be worth consideration whether they can be utilized in breeding.

The term early maturity, however, appears to be used also in a quite different sense, referring to the conformation of the animal rather than to completed growth. Thus, if a steer at 22 months has attained the typical beef form and reached sufficient size to meet the demands of the market, he is said to be mature. Obviously, this does not mean that he has completed his growth, but simply that he has made sufficient growth to furnish marketable meat. This conception of maturity, in other words, is commercial rather than physiological. It is important to note, however, that it involves a physiological element. A certain size of carcass as well as a certain conformation is demanded, and to reach this at an early age almost necessarily implies a greater rate of growth, whether measured physiologically by increase of protein tissue or practically by gain in weight.

It is perhaps possible to combine these two points of view into a single statement, somewhat as follows: The greater the initial impulse to growth, the sooner and the more cheaply will the animal reach physiological maturity, while if the rate of growth can be made sufficiently rapid the desired accumulation of meat, and consequent weight, may be reached before physiological maturity. In other words, the matter reduces itself to the question of rate of growth. The more rapid this is the more fully we can take advantage of the very marked assimilative power of the young animal for protein, while at the same time diminishing the relative cost for maintenance.

For these reasons, and in part also on account of changing market demands as to weight of carcass, there has been a steady tendency toward marketing meat animals at an earlier and earlier age, and it may be safely predicted that this tendency will continue until the natural limits of early maturity are reached.

FEEDING CAPACITY.

It is a well-recognized fact that very marked differences exist between different individual animals as regards the returns made for the feed consumed; but when we come to inquire into the causes of these differences we find a great dearth of definite information and a considerable variety of opinion.

Digestive power.—The superiority of one breed or animal over another as regards feeding capacity is often ascribed to a difference in the extent to which the feed is digested, although those who make this assertion often understand by digestion what is more properly termed "utilization." Undoubtedly there are differences in digestive power between different animals, but except in the case of manifestly abnormal animals they have been found to be comparatively slight and quite insufficient to account for the marked differences in production. Neither is there any evidence that the improved breeds of meat-producing animals possess any superiority in this respect over the ordinary unimproved animals.

It is to be remembered, however, that digestion experiments, for obvious reasons, have usually been made upon relatively light rations. It is possible that upon full feed the better animal would show a superiority over the poorer one in this respect which is not manifest on lighter rations, although the recorded data regarding feed requirements per unit of gain do not seem to favor this view.

Assimilative power.—By this term we may designate broadly the ability of the organism to convert the digested nutrients of the feed into body tissue. Is the good meat producer able to form from a unit of digested feed of a given kind more new tissue than can the inferior animal? In other words, is the percentage utilization of the feed above the maintenance requirement affected by the individuality of the animal? As yet there has been scarcely any scientific investigation bearing on this question. It is worth noting, however, that such of the Moeckern experiments as were made upon similar feeding stuffs with different animals show a generally good agreement as regards the utilization of the energy of the feed, although it does not appear from the accounts of the experiments whether or not the animals used differed materially in type.

In the aggregate a considerable number of breed tests of cattle, sheep, and swine have been made by the American experiment stations, the results of which have been summarized by Henry[a] so as to show the quantity of feed consumed per unit of gain. While in individual cases considerable fluctuations are to be found, nevertheless the results as a whole certainly fail to indicate any marked superiority of one breed over another in this respect, and later experiments have not given materially different results. When we come to consider the other possible factors, such as differences in live weight, in maintenance requirement, in total feed consumed, etc., we must conclude that the recorded results give no clear evidence of any specific individual or breed differences in the actual physiological processes involved in the conversion of feed into tissue, although it is equally true, of course, that they fail to prove the absence of such differences.

On the whole the probabilities seem to be that individual differences in assimilative power, in the sense in which the term is here used, if they exist at all, are not an important factor in meat production.

The maintenance requirement.—Another possible cause of the varying results obtained with different animals is variation in the amount of feed required for maintenance. It is obvious that if, of two animals receiving identical rations, one uses 50 per cent and the other 60 per cent for simple maintenance, the gains by the two, all other conditions being the same, will be in the proportion of 50 to 40. The current method of comparing the gain directly with the total feed consumed (i. e., of computing the gain per 100 pounds of feed or the feed consumed per 100 pounds of gain) entirely ignores this possible difference, which may be one of the causes operating to produce the variations in individual results in the breed tests just referred to.

The recorded results on the maintenance requirements of cattle do not seem to indicate any striking individual differences, but their number is comparatively limited. One factor in particular, which may conceivably affect the results of experiments on meat production more markedly than it would determinations of the maintenance requirement, is the greater or less degree of activity of the animal. In most maintenance experiments the latter has been necessarily more or less restricted, while under the conditions of practice it may perhaps have a considerable influence. The large expenditure of energy in all forms of muscular activity, even in simple standing, is a familiar fact. The restless, nervous animal is rarely a good feeder, because it expends too large a proportion of its feed in doing useless work, while the quiet animal that is inclined to "eat and lie down" may show much better economic results without possessing any specifically greater ability to convert surplus feed into meat. It simply has a larger surplus from a given amount of feed.

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[a] Feeds and Feeding, second edition, pp. 373, 488, 545.

Feed consumption.—Another important element in the problem, and one closely related to the preceding, is the ability of the animal to consume regularly large amounts of feed. Of two animals otherwise similar, it is clear that the one which is able to consume day after day the larger amount of feed has the advantage as a meat producer, but it is not always so clearly seen that the heavier feeder makes a relatively more profitable use of his feed. If we suppose, for example, that two fattening steers, each weighing 500 kilograms, are supplied with exactly a maintenance ration of hay, equivalent in each case, let us say, to 12,000 calories of metabolizable energy, it is clear that the one which is able to eat and digest more corn will make the more rapid gain. Let us suppose these amounts of corn consumed respectively to contain 8,000 and 6,000 calories of metabolizable energy. About 53 per cent of this energy is utilizable, and the gains will therefore be about 4,240 and 3,180 calories, respectively, and we have the following results:

Relative production on different amounts of feed.

	Steer No. 1.	Steer No. 2.
	Calories.	*Calories.*
Maintenance	12,000	12,000
Excess feed	8,000	6,000
Total feed	20,000	18,000
Gain	4,240	3,180
Total gain per 100 calories	21.20	17.67

In other words, the productive part of the ration forms a larger part of the total ration in the case of the large eater, and since all the feed must be paid for, this animal makes the more economical gain, not because he utilizes his excess feed better, but simply because he is able to consume more of it.

There is no doubt that there are marked differences between individual animals in this respect. Whether the specific meat-producing breeds as a whole possess any advantage in this respect appears doubtful in view of the results on record regarding the feed cost of gain with different breeds (see p. 46). The quality is one to which the attention of breeders has not been particularly directed, yet it is one which, it would seem, might well repay attention.

AGE OF ANIMAL.

The subject of early maturity leads naturally to a consideration of the influence of the age of the animal upon the rate and profits of meat production, a subject which requires somewhat careful consideration to avoid confusion of ideas.

In the first place it is essential to distinguish between the normal rate of growth of an immature animal and the more rapid increase in weight which may be brought about by heavy feeding. The former is not, it is true, easy to define sharply, but in a rather broad way we may say that it is the gain due to the normal rate of growth of protein tissue plus such amounts only of fat as may be regarded as necessary in a well-nourished body. We shall consider in the first place the influence of the age of the animal upon this normal rate of growth.

GAIN MOST RAPID IN YOUTH.

It has become a commonplace that animals gain most rapidly in youth. Thus the young calves experimented on by Soxhlet (see p. 13) gained per day and head from 1.65 to 2.77 pounds live weight. Wolff[a] cites the results of a feeding experiment with three calves, 14 days old, in which the daily gain in weight ranged from 1.14 to 3.38 pounds. Henry[b] cites numerous experiments with calves by different investigators in which the daily gain per head ranged from 1.43 to 2.08 pounds. While, as has just been said, these gains by growing animals are not strictly comparable with those of fattening animals, it may help us to appreciate the significance of the above figures to recall that they are scarcely inferior to the gains made by mature cattle of ten or twelve times the weight of the calves, when on full feed.

Even more striking gains are shown by young pigs. Thus Henry[c] gives the gain per day and head of sucking pigs, on the average of 12 litters, as ranging from 0.27 pound in the first week to 0.77 pound in the tenth week. Lambs show similar results. Henry[d] fed four 10-day-old lambs for twenty-one days on cows' milk and obtained an average daily gain per head of 0.46 pound. Shepperd[e] found the daily gain of four sucking lambs to range from 0.40 to 0.62 pound.

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[a] Landwirtschaftliche Fütterungslehre, p. 152.

[b] Feeds and Feeding, second edition, pp. 334–338.

[c] Ibid., p. 540.

[d] Wisconsin Experiment Station, Report for 1890, p. 12.

[e] Agricultural Science, vol. 6, p. 397. 1892.

If we compute such of the above data as admit of it per 1,000 pounds live weight, we have the following striking results:

Daily gains per 1,000 pounds live weight, by calves, pigs, and lambs of different ages.

Animals and authorities.	Average age.	Gain per 1,000 pounds live weight.
	Days.	*Pounds.*
Calves (Soxhlet)	8	21.60
	15	18.10
	21	18.40
	32	16.30
	18	17.00
Pigs (Henry)	4	78.27
	21	47.62
	67	21.51
Lambs (Henry)	21	21.40

RATE OF GAIN DIMINISHES RAPIDLY.

It is an equally familiar fact that the rate of gain per 1,000 pounds by the young animal diminishes rapidly as it grows older. The table just given illustrates this in the case of young calves and pigs. While the absolute gain per head may increase, as was the case with the pigs, the relative rate of gain diminishes.

Numerous examples may be cited to show that the same law holds for later stages of growth, although it is not in all cases easy to distinguish, from the accounts of the experiments, between the gain due to growth proper and that due to fattening. Johnson [a] reports the average daily gain in weight per head of 10 steers as follows: From birth to 1 year old, 1.94 pounds; from 1 to 2 years old, 1.36 pounds. The cattle are said to have been kept thrifty but not fattened.

Henry [b] fed calves averaging about 10 weeks old for two years with the following results:

Gains by growing cattle.

Number of animals.	Period.	Average live weight.	Gain per day.	
			Per head.	Per 1,000 pounds live weight
		Pounds.	*Pounds.*	*Pounds.*
16	Period I, 98 days	201	1.63	8.11
	Period II, 84 days	332	1.22	3.68
	Period III, 84 days	430	1.10	2.56
	Period IV, 42 days	492	0.77	1.57
12	Period V, 212 days	652	1.35	2.07
	Period VI, 64 days	878	2.46	2.80
10	Period VII, 88 days	1,007	0.82	0.81
	Period VIII, 57 days	1,079	1.25	1.16

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[a] Michigan Experiment Station, Bulletin 44, pp. 8-10.

[b] Wisconsin Experiment Station, Third Report, p. 25; Fourth Report, p. 44.

Notwithstanding the considerable fluctuations in the rate of gain, the high figures for the first period and the general decrease in the later stages of growth are evident.

Goessman[a] found the average daily gains per head of two 2-year-old steers and two yearlings on similar rations to be: Two-year olds fed one hundred and forty-four days, 1.20 pounds; yearlings fed one hundred and forty-four days, 1.60 pounds; the same yearlings fed for the succeeding one hundred and forty-four days on pasture, 0.73 pound. No statements are made as to the fattening of the animals, but the rations were only fairly heavy.

NATURE OF GAIN AT DIFFERENT AGES.

The data already given (pp. 30–33) regarding the composition and energy value of the increase at different ages show clearly one important cause, and perhaps the chief one, of the relatively rapid gain in weight by young animals. Such animals, as we have already learned, show a notable power of storing up protein, a power which diminishes rapidly with increasing age. Corresponding to this, we see that a large proportion of the organic matter stored consists of protein. Now the proteid tissues of the body are par excellence the water-holding tissues, and this fact is reflected clearly in the table, which shows the gain of very young animals to contain as much as 80 per cent of water. In other words, a pound of gain by a young animal, as compared with the same gain by a mature animal, contains much less organic matter, and this organic matter itself has a lower energy value, since it contains relatively more protein and less fat. Accordingly, as we see in the extreme case, a gain of 1 kilogram by a nearly mature animal represents the storage of over nine times as much food energy as the same gain by a very young animal.

The data are too fragmentary to permit any general statement as to the relation at different ages, but the general fact is clear. When we add to this the fact that this rapid gain in live weight by the young animal is composed largely of that which the meat producer is aiming for, viz, meat in the limited sense, the great economic advantage of the young animal becomes clear.

RELATIVE GAIN OF ENERGY.

In view of the foregoing facts, it becomes of interest to inquire whether the more rapid gain by the young animal is due wholly to the difference in the composition of the gain, or whether the growing organism has a specifically greater power to store up energy. For this purpose we may compare the rate of gain of energy per unit of live weight, somewhat as we have already compared the gain of protein. The following table contains the few available results:

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[a] Massachusetts State Experiment Station, Report for 1891, p. 107.

Relative gain of energy by animals at different ages.

Experimenter.	Animal.	Average age.	Daily gain of energy per kilogram live weight.
		Days.	*Calories.*
Sanford and Lusk	Pig	7	39.57
Wilson	do	8	29.07
Soxhlet	Calf	8	54.36
Do	do	15	50.14
Do	do	21	47.90
Tschirwinsky	Pig	114	31.72
Do	do	134	44.88
Henneberg et al	Sheep	290	14.76
Do	do	458	14.01
Do	do	521	9.50
Do	do	745	8.64
Jordan	Steer	840	3.16

The large gaps in the table are most unfortunate, but there seems to be a clear indication of a decreasing relative energy of assimilation, expressed in terms of energy, with advancing maturity. The subject is well worth further investigation, however.

GAIN PER UNIT OF FEED.

It should be clearly understood that the greater energy of assimilation just spoken of, if it be a fact, is by no means equivalent to a higher percentage utilization of the energy of the food. The facts given simply indicate that the young animal has the power to store up relatively greater amounts of matter and energy, but give no clue to the expenditure of feed energy required for this purpose. As has already been stated, no satisfactory data are on record regarding the influence of age on the percentage utilization.

In practice, however, results are measured by the gain in live weight, and this, as we have seen, represents a less amount of energy per unit in the young than in the mature animal. Consequently, even if the actual utilization of the energy of feeds of the same character is no greater in the young animal, the gain in weight per unit of feed will be greater. The experiments already cited to illustrate the rate of gain at different ages will serve to demonstrate this fact also, and to these may be added the results obtained by Wilson and Curtiss at the Iowa station.[a] In most of the experiments a variety of feeds was used and in but few of them was the dry matter of the feed determined. It will be convenient, therefore, to make the comparisons on the basis of the cost of feed per unit of gain, using this as a sort of approximate common denominator, the prices estimated for feed being generally uniform in each experiment.

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[a] Iowa Experiment Station, Bulletin 20.

The following table by Henry[a] gives the results of the experiments of Johnson, Goesmann, and Henry, and includes also averages from the records of the fat-stock shows of 1882 and 1883.

Cost of 100 pounds gain in live weight, with steers of different ages.

	1 to 12 months old.		12 to 24 months old.		24 to 36 months old.	
	Number of animals.	Cost of feed.	Number of animals.	Cost of feed.	Number of animals.	Cost of feed.
Fat-stock show, 1882[b]	9	$4.03	5	$7.98	2	$12.54
Fat-stock show, 1883	6	3.70	4	8.12		
Michigan station[c]	10	1.87	10	7.37	10	9.57
Wisconsin station[d]	16	4.20	11	6.13		
Massachusetts station[e]			2	7.49	2	12.38

The Iowa results, omitting the second period, on pasture, were:

Cost per pound of gain by steers at Iowa Experiment Station.

Period.	Age.	Cost per pound of gain.
	Months.	*Cents.*
I	24	5.93
III	31	6.15

As would be expected, the differences are irregular and in some cases small, and they may to a certain extent represent, particularly in the case of the figures from the fat-stock shows, the influence of increased fatness rather than of age. Nevertheless their general teaching is unmistakable.

BEST AGE FOR FATTENING.

The effect of age, as we have seen, is chiefly upon the gain of protein. While we have no evidence that the process of fattening proper is materially affected by this factor, on the other hand growth, which is largely synonymous with the formation of lean meat, goes on much less rapidly and economically as the animal approaches maturity. It is evident, as already pointed out, that the earlier the process of growth can be completed, by the selection of animals with a well-developed capacity for growth and by suitable feeding, the more economically it can be conducted. On the other hand, the process of fattening can, it would appear, be carried out equally well at almost any stage.

Fattening, however, is relatively a more rapid process than growth, and therefore should be begun later. Heavy fattening rations, containing large amounts of nonnitrogenous nutrients, even if they do not interfere with the growth of young animals, are uneconomical, tending either to overload the meat with fat or toward the accumulation of cheap internal fat, and making the animal ripe for the butcher before his capacity for the production of meat has been properly utilized. A limited market exists, of course, for fat lambs and veals; but, for the production of the bulk of the world's meat supply, it is important to utilize the capacity for growth up to a point at least approaching maturity. Such being the case, too early fattening tends to produce an animal which, even if not of inferior quality, must be maintained in a fat condition until the growth of lean meat has had an opportunity to overtake that of fat.

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[a] Feeds and Feeding, second edition, p. 369.

[b] Report of Illinois board of agriculture, 1884.

[c] Michigan Experiment Station, Bulletin 44.

[d] Wisconsin Experiment Station, Report for 1886.

[e] Massachusetts Experiment Station, Report for 1891.

On the other hand, the beginning of the fattening process may be delayed too long. To take the extreme case, it would be obviously uneconomical first to grow the animal to the full degree of maturity required and then to add a fattening period. While we have no reason to suppose that the amount of food actually expended in the production of a unit of gain would be materially greater than if the fattening were conducted during the latter part of the growing period, the expenditure for maintenance, care, interest, etc., would be simply so much added to the cost of production. Plainly the beginning of the fattening should be so timed that it will be completed by the time the rate of gain of lean meat ceases to be profitable under the existing market conditions.

The foregoing assumes, of course, that the animal is both grown and fattened by the same individual, a thing which is true in the minority of cases only. While the same general principles apply also to the fattening of purchased animals, the market is so large a factor in this operation that their application is liable to be very essentially modified or obscured entirely by speculative considerations.

CONDITION.

It is generally admitted that in the case of the nearly mature fattening animal the rate of gain in live weight decreases as the fattening progresses until a limit is reached beyond which the increase, if obtained at all, is slow and very costly. Several causes are responsible for this:

First. The maintenance requirement of the animal increases with its gain in weight, as has been shown by Kellner.[a] The capacity of the digestive organs, however, undergoes no corresponding increase, and consequently, as pointed out in a previous paragraph, not only is the amount of excess feed correspondingly reduced but its proportion in the ration is made less, so that the total feed requirement per unit of gain will be greater.

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[a] Die Landwirtschaftlichen Veruchs-Stationen, bd. 50, p. 245.

Second. The appetite of well-fattened animals not infrequently diminishes, resulting in a lessened consumption of feed. This again has a double effect, diminishing the total amount of excess feed available and reducing the proportion of excess feed to total feed.

Third. It seems probable that a unit gain in live weight toward the close of the fattening period represents a larger storage of energy than the same gain at its beginning.

For all these reasons it is natural that the "condition" of the animal—that is, its state of fatness—should have a marked effect on the rate and economy of gain. Georgeson[a] reports the following results for a lot of 3-year-old grade Shorthorn steers, the number of days given in the table meaning in each case the number from the beginning of the feeding:

Grain consumed by steers per pound of gain at Kansas Experiment Station.

Number of days fed.	Grain consumed per pound of gain.
	Pounds.
56	7.30
84	8.07
112	8.40
140	9.01
168	9.27
182	10.00

Henry[b] reports the following similar results for fattening swine:

Influence of length of fattening period on the feed consumption and gain of hogs at the Wisconsin station.

	Average weight.	Average weekly gain.	Feed eaten during week per hog.	Feed for 100 pounds of gain.	
				By weeks.	By four-week periods.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
First week	222	11.4	41	362	418
Second week	235	13.3	48	362	
Third week	246	10.5	50	475	
Fourth week	257	10.7	50	473	
Fifth week	270	13.9	51	368	461
Sixth week	281	10.1	51	510	
Seventh week	294	13.1	51	391	
Eighth week	303	8.9	51	572	
Ninth week	313	10.5	52	499	559
Tenth week	322	8.9	52	587	
Eleventh week	332	9.6	52	549	
Twelfth week	340	8.8	52	598	

On the other hand, Mumford,[c] in large-scale feeding experiments with cattle, has failed to note any such marked diminution of the gain during the later stages of feeding as has been generally found by other experimenters.

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[a] Kansas Experiment Station, Bulletin 34, p. 95.

[b] Feeds and Feeding, second edition, p. 555.

[c] Illinois Experiment Station, Bulletin 103, p. 57.

There is no sufficient evidence on record to show whether or not the actual percentage utilization of the excess feed diminishes with the advance of fattening.

FEED REQUIREMENTS FOR MEAT PRODUCTION.

The feed requirement of the meat-producing animal is of a dual character: First, there must be a sufficiency of protein to replace the amounts katabolized in the vital processes and to supply material for new growth. Second, the animal must receive an amount of potential energy in available form sufficient to maintain the normal activities of the body and to leave a surplus for storage in the form of flesh and fat.

PROTEIN.

As regards the protein supply, there is necessarily a physiological minimum, but as yet we are far from being able to formulate it with exactness. On previous pages an approximate estimate was attempted of the rate at which protein growth takes place at different ages, while from other sources some idea of the maintenance protein requirements for animals of different weights can be formed. When these two requirements were added together, however, it was found that their sum was notably less than what practical experience indicates to be necessary; and we were led to conclude that protein is required for some other purpose, possibly in connection with the more active metabolism in the growing or fattening animal.

This conclusion, however, leaves us for the present dependent upon the results of ordinary feeding experiments and of experience for our conclusions as to the protein requirements for meat production. Few or no experiments directed specifically to the determination of the protein requirements of growing animals of different species and at different ages are on record. The investigations recorded and considered on previous pages in discussing the laws of growth do, it is true, include data as to the amounts of digestible protein consumed by the animals, but while it seems probable that these were ample in most or all cases to secure a normal growth, there is no evidence that a smaller quantity of protein would not have been equally effective. A considerable amount of material along the same line awaits the compiler in the form of records of practical experiments in feeding growing animals, from which it should at least be possible to compute what amounts of protein are actually used by good feeders.

There is likewise a considerable number of experiments in which rations of different nutritive ratios have been compared in their effects on the gain in live weight of fattening animals. If in such an experiment, in which the total amounts of feed consumed do not differ widely, we find that the wider nutritive ratio has been as efficient as the narrower as regards gain in live weight, and if the gain appears to be normal in amount, there is a strong presumption that the lesser amount of protein in the wider ration was at least sufficient for the needs of the animal. If a block test shows a normal character of growth, this presumption is further strengthened. Furthermore, if we find that rations considerably poorer in protein than the current standards call for give good results in actual practice, the probability is that they contain a sufficiency of protein. Obviously data of this sort can not fix the lower limit of protein supply, but they may furnish a basis for the formulation of rules for practice.

The writer has attempted to bring together on subsequent pages what seems to be the more valuable of the readily available data, but the critical study of the entire mass of material on record is beyond the strength of a single investigator, although the task seems one well worth accomplishment.

ENERGY.

In addition to the protein necessary for maintenance and growth, the meat-producing animal requires sufficient total feed to support the bodily activities and leave a surplus for the production of a certain amount of adipose tissue. It has been shown that all the chief ingredients of the digested feed may serve for this purpose, and the amount of material thus available may be conveniently expressed in terms of energy. The most rational basis of comparison would seem to be what has been designated as net available energy, but since so few determinations of availability have been made it will be more convenient to base the discussion upon the so-called metabolizable energy, or "fuel value."

It is clear at the outset that we can not speak of the energy requirement for meat production in the same sense that we can of the protein requirement. In the latter case there is a certain natural rate of increase of protein tissue for which material must be supplied. In the former case, assuming the protein supply to be sufficient, it is, except as protein may be necessary for the more active metabolism incident to fattening, simply a question of a greater or less production of fat, or, in other words, of the rapidity of the process. This, however, is quite as much an economic as a physiological question. Is it more profitable to seek the most rapid increase possible, or will a more moderate rate of gain yield a greater return for the feed invested?

FATTENING.

In the discussion of feed requirements for meat production we have to distinguish between the standpoint of the man who buys nearly mature animals and prepares them for the market by a relatively brief fattening process, and that of the man who grows meat animals from birth. The latter, again, may market his animals in the unfattened condition as "stockers," as is largely the case with cattle in the United

States, or he may combine growth and fattening and aim to put his animals on the market in condition for the butcher, as is ordinarily done with hogs. For convenience, we may take the former case first, as being in some respects the simpler.

Under present conditions in the United States but a small proportion of the fat cattle marketed at the large centers of the trade have been grown and fattened by the same owner. Thus Mumford[a] estimates that only about 15 per cent of those marketed in Chicago are carried from birth to maturity without changing hands. The fattening of the other 85 per cent is substantially a commercial undertaking, involving a considerable element of speculation, and the time consumed in the fattening becomes an important element in determining the profit of the transaction. While the producer of "stockers" has simply to see to it that his animals secure sufficient feed to supply the demands of normal growth, the feeder of fat cattle desires to push the fattening to the limit set by considerations of cost. This he has to accomplish by the use of relatively expensive feeds; hence, the question of feed requirements and of the most complete utilization of feeds becomes a very vital one.

Substantially the same general considerations apply to mutton production as to beef production, while with swine, on the other hand, growth and fattening are more commonly combined.

PROTEIN REQUIREMENTS.

Mature animals.—Abundant data exist to show that the protein requirements of mature fattening animals as formulated in Wolff's feeding standards have been greatly exaggerated. So far as protein is concerned these standards appear to have been based upon the then prevailing views as to the source of animal fat rather than upon actual experimental investigation. Indeed, Wolff himself has demonstrated the excessiveness of the protein requirement as regards sheep. In 1890 he published[b] the results of a comparison made in 1885–86 of maize and beans as feed for fattening sheep, using two lots of two mature sheep each. After a preliminary feeding, the following results were obtained in 107 days' feeding:

Influence of protein supply on gain by mature fattening sheep.

Items.	Lot 1, fed on hay and beans.	Lot 2, fed on hay and maize.
	Kilograms.	*Kilograms.*
Weight at beginning	99.93	98.61
Weight at close	118.75	118.56
Gain	18.82	19.95
Digestible matter eaten per 1,000 kilograms live weight:		
Protein	3.26	1.81
Total digestible (fat × 2.4)	18.19	19.20

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[a] Illinois Experiment Station, Circular 79.

[b] Landwirtschaftliche Jahrbücher, bd. 19, p. 823.

The lot receiving maize is seen to have produced about the same gain relatively to the digestible matter consumed, notwithstanding the smaller amount of protein supplied. A block test tended to show a slight superiority on the part of lot 2. Similar experiments made in 1892 and published in 1896[a] gave confirmatory results, barley being compared with beans on one animal each. The following table shows the actual digestible nutrients, computed per 1,000 kilograms live weight, and the total gain for each period:

Influence of protein supply on gain by mature fattening sheep.

Period.	Number of days.	Sheep No. 1 fed on barley.			Sheep No. 2 fed on beans.		
		Total gain.	Digested per 1,000 kilograms live weight.		Total gain.	Digested per 1,000 kilograms live weight.	
			Protein.	Total nutrients.		Protein.	Total nutrients.
		Kilograms.	*Kilograms.*	*Kilograms.*	*Kilograms.*	*Kilograms.*	*Kilograms.*
III	29	1.6	1.62	14.69	2.4	3.13	16.12
IV	20	1.4	1.63	15.23	.9	2.95	16.02
V	38	4.0	2.03	17.32	3.6	3.61	16.32
Total		7.0			6.9		

In the final period of Weiske's experiments with lambs,[b] described on page 16, the animals, then 2 years old, received an exclusive hay ration from which they digested 1.22 kilograms of protein per 1,000 kilograms live weight. While no material fattening was possible on such a ration, there was still a gain of protein nearly as great per head as in earlier periods, thus rendering it probable that the protein supply was at least nearly sufficient for a moderate rate of fattening.

On the basis of these results we shall hardly go far astray if we say that 1.5 pounds of digestible protein per 1,000 pounds live weight is at least sufficient for mature fattening sheep. Whether this could be further reduced does not appear.

Lehmann[c] has reported briefly an experiment with sheep in which 400 kilograms of cotton-seed meal was fed to one lot and 450 kilograms of maize to a comparison lot, along with coarse fodder, the respective gains being 39.6 and 39.67 kilograms. The data are insufficient for a computation of the digestible matter of the rations. Funke[d] also reports an interesting case of the satisfactory fattening of mature cattle on potatoes and straw, but gives no numerical data.

Kellner's extensive respiration experiments with cattle at Moeckern have shown[e] that no larger proportion of energy is stored from protein than from fat or carbohydrates. This is equivalent to saying that the excess feed is no more efficient for fattening when it contains much protein, and the only question remaining is whether any larger proportion of the resulting gain consists of protein. To test this question, the reported results of the experiments have been grouped according to the amount of digestible protein (N.×6.25) fed, yielding the following averages per day and head:

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[a] Ibid., bd. 25, p. 175.

[b] Ibid., bd. 9, p. 205.

[c] Ibid., bd. 30, Supp. II, p. 162.

[d] Journal für Landwirtschaft, bd. 41, p. 208.

[e] Die Landwirtschaftlichen Versuchs-Stationen, bd. 53, p. 469.

Percentage of protein in gain by mature fattening cattle.

Group.	Number of experiments.	Average live weight.	Digestible protein fed.		Gain.		Protein in gain.
			Range.	Average.	Protein.	Fat.	
		Kilos.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Per cent.*
I	7	656	280- 399	343	57.2	400.2	12.50
II	14	651	400- 599	485	53.6	403.5	11.73
III	18	667	600- 799	713	87.4	440.9	16.54
IV	11	671	800- 999	894	103.3	507.8	16.91
V	10	691	1,000-1,830	1,497	108.5	521.0	17.24

Apparently the tendency of the larger protein supply in the feed was to increase somewhat the proportion of protein in the gain, even with these fully mature animals (6 to 8 years old). As noted on page 31, however, the periods covered only two to four weeks, and it may be questioned how long this gain of protein would have continued. In other words, we are again confronted with the question whether any considerable gain of protein is possible in mature animals.

The periods being short in these experiments, the effect of the different rations on the live weight can not be satisfactorily determined, and therefore the results are not fully comparable with those previously given nor with those to be considered later. It is evident, however, that very satisfactory results may be attained with mature cattle on rations containing scarcely more protein than is required for maintenance, as is evident when we compute the digestible protein in the above experiments per 1,000 kilograms live weight, viz:

	Kilograms.
Group I	0.523
Group II	.745
Group III	1.069
Group IV	1.332
Group V	2.167

Loges [a] reports the results of experiments, undertaken at Pomritz to test Kellner's conclusions, in which a nutritive ratio of 1:10.3 gave as great gains in weight with mature cattle as one of 1:5.7, but the absolute amounts of protein consumed are not stated in the abstract.

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[a] Biedermann's Central-Blatt für Agrikulturchemie, etc., bd. 31, p. 646.

Apparently from 0.75 to 1 kilogram of digestible protein per 1,000 kilograms live weight is amply sufficient to meet the requirements of fully mature fattening cattle.

Immature animals.—By far the larger share of the meat production of the United States is derived from animals that have not reached full maturity, the feeder planning, consciously or unconsciously, to take advantage of the capacity for growth of the immature animal and thus to combine to a certain degree growth and fattening.

For years feeders in the corn belt of the United States have been fattening nearly mature cattle, sheep, and hogs chiefly on Indian corn, using rations that can hardly have had a narrower ratio than 1:10, and must often have been much wider. It would be foolish to assert that these feeding practices have always been the most rational. There is little doubt that more and better, and possibly cheaper, meat might often have been produced had more protein been supplied, but it nevertheless remains true, in a broad way, that at least fairly satisfactory results have been and are being reached on rations containing scarcely half the protein called for by the Wolff standard for mature animals. At the same time, accurate numerical data as to the rations fed in practice are not easily obtained.

The earliest American experiments on the protein requirements of fattening cattle of which the writer has knowledge are those of Jordan[a] in 1881–1885, in which the value of cotton-seed meal as an addition to corn meal was tested. The following tabulation gives such of the results of the experiments as bear on the present discussion. When necessary, the digestible protein of the rations has been computed by the writer, while as an approximate measure of the total quantity of food (energy) in the rations their "production values" have been computed from Kellner's table.

Comparison of corn-meal with corn-meal and cotton-seed-meal rations for fattening cattle.

	Per day and 1,000 pounds live weight at beginning of period.	
	Corn-meal ration.	Corn-meal and cotton-seed-meal ration.
1881–82.		
Eastern farm,[a] ninety-seven days:		
Digestible protein ... pounds	1.06	2.08
Production value ... calories	13,620	12,730
Gain in weight ... pounds	1.28	1.84
Central farm, eighty-four days:		
Digestible protein ... do	1.24	2.17
Production value ... calories	16,070	12,330
Gain in weight ... pounds	1.135	1.602
Relative gains ... do	100	149
Relative gains on preliminary feeding ... do	100	144

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[a] Pennsylvania State College, Bulletins 6 and 10; Report for 1886, p. 175.

Comparison of corn-meal with corn-meal and cotton-seed-meal rations for fattening cattle—Continued.

	Per day and 1,000 pounds live weight at beginning of period.	
	Corn-meal ration.	Corn-meal and cotton-seed-meal ration.
1882–83.		
First period, forty-nine days:		
Digestible protein ... pounds	1.09	1.80
Production value ... calories	14,220	10,710
Gain in weight ... pounds	1.675	1.172
Second period, forty-two days:		
Digestible protein ... do	1.16	1.87
Production value ... calories	14,310	11,420
Gain in weight ... pounds	1.767	1.557
1883–84.		
2-year-olds, seventy-seven days:		
Digestible protein ... pounds	1.38	2.20
Production value ... calories	15,870	13,440
Gain in weight ... pounds	2.42	2.79
3-year-olds, seventy-seven days:		
Digestible protein ... do	1.26	2.10
Production value ... calories	13,900	12,180
Gain in weight ... pounds	1.49	1.51
4-year-olds, seventy-seven days:		
Digestible protein ... do	1.31	2.15
Production value ... calories	13,480	12,250
Gain in weight ... pounds	1.54	[b].86
1884–85.		
2-year-olds, sixty-three days:		
Digestible protein ... pounds	1.60	1.74
Production value ... calories	13,340	10,280
Gain in weight ... pounds	2.00	2.05
3-year-olds, sixty-three days:		
Digestible protein ... do	.94	1.63
Production value ... calories	12,500	10,050
Gain in weight ... pounds	1.76	1.97

Assuming, according to Kellner, a requirement of 6 pounds of starch equivalent, equal to 6,426 calories production value, for maintenance, the experiments of 1881–82 and 1882–83 show an advantage on the side of the higher protein, but the difference is much less marked in 1882–83, when the cattle are said to have been older, although the ages are not stated.

The experiments were continued by Frear[c] in 1885–86 on the same general plan, but with greater elaboration of detail. Two lots of two 3-year-old steers received per 1,000 pounds live weight rations containing the following amounts of digestible protein per day as determined by digestion experiments: Steers 2 and 3, Period II, 1.61 pounds; Period III, 1.69 pounds. Steers 1 and 4, Period II, 0.79 pound; Period III, 0.93 pound. The apparent advantage was on the side of the low protein rations, but the periods were short and there was no close agreement between the individual animals.

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[a] Average of two periods in which the rations of the two lots were interchanged.

[b] Animals not thrifty.

[c] Pennsylvania State College, Report for 1886, p. 180.

Two lots of 2-year-old steers gave the following results per day per 1,000 pounds live weight:

Gains by 2-year-old steers on a corn-meal ration and on a cotton-seed meal ration.

	Results with corn-meal ration.	Results with cotton-seed-meal ration.
Digestible protein.....pounds..	1.13	1.73
Production value.....calories..	14,980	10,730
Gain in weight.....pounds..	1.314	1.392

In almost every case the gain per unit of "production value" is greater on the high-protein ration, especially if we deduct the probable maintenance requirement and make the comparison on the basis of the excess feed. We may fairly attribute this greater increase to a greater growth of meat, with its large percentage of water, made possible by the larger protein supply. Apparently a ration of from 1 to 1⅓ pounds of digestible protein (N.×6.25) per day per 1,000 pounds live weight is insufficient to insure the normal growth of meat in steers 2 to 3 years old.

Some comparatively recent experiments at the Missouri Experiment Station[a] tend to confirm these early Pennsylvania results. They have thus far been published only in outline,[b] and in particular the weights of the animals are lacking, so that the comparison per 1,000 pounds live weight can not be made.

Results in feeding steers at the Missouri Experiment Station.

Animals and rations.	Digestible protein of ration.	Production value of ration.	Gain in weight per day.
	Pounds.	*Calories.*	*Pounds.*
Yearling steers:			
Timothy hay.....	0.45	7,284	[c] 30.8
Corn stover and clover hay.....	.93	7,723	[c] 58.4
Yearling steers, 1899:			
Corn and timothy hay.....	.57	8,624	0.64
Corn stover and clover hay.....	.93	8,968	0.86
Corn and cowpea hay.....	2.01	11,323	1.54
Yearling steers, 1900:			
Corn and timothy hay.....	.69	10,097	1.00
Corn and clover hay.....	1.37	11,541	2.00
Corn stover and clover hay.....	1.15	11,166	1.35
2-year-old steers, 1899-1900, full feed:			
Corn and timothy hay.....	1.45	20,040	1.69
Corn and cowpea hay.....	2.30	22,942	2.64
Corn, clover hay and corn stover.....	1.71	21,577	1.94
2-year old steers, 1900-1901, full feed:			
Corn and timothy hay.....	1.51	20,689	1.97
Corn and clover hay.....	2.17	24,814	2.84
Corn and cowpea hay.....	2.78	25,637	2.84
Clover hay and corn stover.....	1.92	23,466	2.85
Clover hay and wheat straw.....	1.97	22,919	2.68

If we may assume an average live weight of 700 pounds per head for the yearlings and of 1,000 pounds per head for the 2-year-olds, the minimum requirement for 2-year-olds would seem to be somewhat higher than that indicated by the Pennsylvania experiments, viz, more than 1.5 pounds, while that for yearlings is apparently fully 2 pounds per day per 1,000 pounds live weight.

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[a] Monthly Bulletin Missouri Board of Agriculture, September, 1901; University of Missouri, Circular of Information No. 11.

[b] Further data regarding the experiments on yearlings have appeared in Bulletin 75 of the Missouri Station.

[c] Total for experiment.

Mumford[a] has compared a ration of corn, timothy hay, and corn stover with rations in which on the one hand clover hay was substituted for the corn stover and timothy hay, and on the other hand gluten meal replaced part of the corn, the animals being native steers, weighing about 970 pounds, and of common to medium quality, fed in carload lots. The bulletin states the total feed consumed during the eighteen weeks of the experiment. The average daily ration should therefore be compared with the live weight at the middle of the experiment. Using average figures, the writer has computed the digestible matter and production values of these rations as follows:

Feed consumed per 1,000 pounds live weight.

Lot.	Ration.	Dry matter.	Digestible matter in ration.				Production values.
			Protein.	Carbohydrates.	Fat.	Total (fat × 2.25).	
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Calories.*
1	Corn and clover hay	23.86	1.79	14.81	0.85	16.72	17,350
2	Corn, timothy hay, and corn stover	22.19	1.24	14.50	.75	16.20	16,480
3	Corn, gluten meal, timothy hay, and corn stover	21.02	1.49	13.01	.88	14.97	15,160

These rations produced the following average daily gains:

Average daily gains per head and per 1,000 pounds live weight.

	Per head.	Per 1,000 pounds live weight.
	Pounds.	*Pounds.*
Lot 1	2.510	2.21
Lot 2	1.858	1.70
Lot 3	2.268	2.01

Assuming a maintenance requirement of 6 pounds of total digestible matter per 1,000 pounds live weight, or 6,426 calories production value, the excess feed per pound of gain was as follows:

Excess feed per pound of gain.

	Excess feed.	
	Weight.	Production value.
	Pounds.	*Calories.*
Lot 1	4.66	4,940
Lot 2	5.71	5,910
Lot 3	4.21	4,340

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[a] Illinois Experiment Station, Bulletin 83.

It appears evident that the 1.24 pounds of protein per 1,000 pounds live weight in the ration of lot 2 was insufficient for the maximum increase. Lot 1 gained notably more than lot 3, but also consumed more feed, so that the excess feed of lot 3 appears to have been somewhat more efficient than that of lot 1, while in both cases it gave much better results than with lot 2.

In a later experiment by the same investigator,[a] comparing methods of preparing feeds, in which choice 2½-year-old cattle were fed in lots of 10 or 15 each for one hundred and eighty-six days, results were obtained bearing on the subject under discussion. The published figures do not admit of a ready computation of the energy values of the rations, but from data kindly furnished by Professor Mumford the average digestible matter per 1,000 pounds live weight at the middle of the experiment has been computed. The table includes also the average daily gain of live weight per head and per 1,000 pounds.

Average digestible matter and gain per head and per 1,000 pounds live weight.

Lot.	Feeds.	Digestible matter per 1,000 pounds live weight.			Daily gain.	
		Protein.	Carbohydrates + (fat × 2.25).	Total.	Per head.	Per 1,000 pounds live weight.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	Corn meal, gluten meal, oil meal, silage, and clover hay	1.71	13.63	15.34	2.34	1.90
2	Ear corn, gluten meal, oil meal, and clover hay	1.99	15.49	17.48	2.33	1.85
3	Ear corn broken, clover hay	1.49	15.52	17.01	2.08	1.73
4	Corn meal, gluten meal, oil meal, and clover hay	1.90	14.84	16.74	2.38	1.95
5	Corn meal, gluten meal, oil meal, and chaffed hay	1.86	14.48	16.34	2.33	1.86
6	Corn and cob meal, gluten meal, oil meal, and clover hay	1.76	15.46	17.22	2.32	1.87
7	Corn and cob meal, gluten meal, oil meal, and clover hay	1.79	15.87	17.66	2.45	2.00
8	Ear corn, oil meal, shock corn, and clover hay	1.67	15.40	17.07	2.08	1.69
9	Shelled corn, gluten meal, oil meal, and clover hay	2.13	14.86	16.99	2.02	1.66
10	Shelled corn, gluten meal, oil meal, and clover hay	2.13	14.88	17.01	1.99	1.64
	Average of lots 1, 2, 4, 5, 6, and 7	1.84	14.96	16.80	2.36	1.90
	Average of lots 3 and 8	1.58	15.46	17.04	2.08	1.71
	Average of lots 9 and 10	2.13	14.87	17.00	2.01	1.65

The daily gain approaches 2 pounds per 1,000 pounds live weight, and is notably uniform except in lots 3, 8, 9, and 10, which show distinctly lower results. Mumford compares especially lots 2 and 3, receiving rations most nearly comparable as to kind of feed, and attributes the difference to the lower protein content of the ration of lot 3. The ration of lot 8, too, was not widely different from that of lot 3. On the other hand, lots 9 and 10, which also gave smaller gains, consumed more protein than any of the others. The pen of lot 9 differed from the others in being unpaved and muddy, which may possibly have influenced the gains, but there is no evident reason for the lower gains of lot 10. On the whole, however, the results seem to indicate that to obtain the maximum growth cattle of this age require more than 1.5 pounds of digestible protein per 1,000 pounds weight, agreeing in this respect with the earlier experiment.

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[a] Illinois Experiment Station, Bulletin 103.

Scheneidewind[a] reports some interesting results of experiments at Lauchstädt, undertaken to test Kellner's conclusions as to the protein requirements in fattening. Two experiments were made, one on two lots of 7 East Prussian cattle 24 months old, and one on two lots of 10 Simmenthal cattle 18 months old, each experiment being divided into two periods. The results were as follows, per 1,000 pounds live weight per day:

Daily gains from feeding a high-protein and a low-protein ration compared.

	Results with—	
	Low-protein ration.	High-protein ration.
2-YEAR-OLD CATTLE.		
Period I, one hundred and thirty-three days:	*Pounds.*	*Pounds.*
Digestible protein	2.0	3.0
Total nutrients	17.0	18.0
Gain	2.57	2.46
Period II, sixty-three days:		
Digestible protein	1.58	2.64
Total nutrients	15.80	15.80
Gain	2.23	2.08
18-MONTHS-OLD CATTLE.		
Period I, one hundred and thirty-three days:		
Digestible protein	2.0	3.0
Total nutrients	17.0	18.0
Gain	3.08	2.95
Period II, sixty-three days:		
Digestible protein	1.58	2.64
Total nutrients	15.80	15.80
Gain	2.33	2.76

In a general way, these results are in accord with those previously quoted in indicating a protein requirement in the neighborhood of 1.5 pounds or perhaps 1.75 pounds per 1,000 pounds live weight for 2-year-old cattle, and of at least 2 pounds per 1,000 pounds live weight for younger animals. Kellner[b] recommends 2 pounds per 1,000 pounds live weight for 2 to 3 year old cattle.

Influence of protein supply on quality of meat.—In discussing the influence of the fattening process on the composition of the lean meat, it has already been shown that there appears to be usually an increase in the soluble protein and extractives. There is no clear evidence that an abundant supply of protein in the feed favors this increase. In view, however, of the storage of nitrogen in mature animals, shown especially by Kellner's results as summarized above, we shall be inclined to answer the question in the affirmative pending further experiments. At the same time, it may be questioned whether this is a very important factor in determining the commercial quality of meat.

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[a] Landwirtschaftliche Jahrbücher, bd. 31, p. 941.

[b] Loc. cit., p. 460.

TOTAL FEED.

Assuming that the feeder has made such a selection of feeds as will insure a sufficient protein supply, the question of the most profitable amount of feed is of the utmost importance. Shall he seek to secure the most rapid gain possible, or will a more moderate rate of fattening yield a greater return on the investment? Obviously this question is not capable of a categorical answer unless all the economic conditions are stated, but it may be profitable to indicate some of the conditions which will determine the answer.

Different quantities of the same ration.—As the simplest case, we may consider first the effect of feeding varying amounts of the same feeding stuff or mixture of feeding stuffs—as might be done, for example, by the use of "cut feed." In this way we may avoid the complications incident to the varying availability and utilization of different feeds.

The percentage utilization of the metabolizable energy of a feeding stuff for meat production is probably constant within at least quite a wide range as regards the amount fed. Each additional unit of energy consumed, then, will produce the same actual storage of energy in the tissues of the animal. A certain amount of the feed, however, is required simply to maintain the animal. Consequently, as has already been shown in discussing the influence of the individuality of the animal as manifested in its maintenance and its feed consumption, the larger the amount of feed eaten the larger is the proportion of it which is available for production and the greater the gain per unit of total feed. Under these conditions it is plain that the more liberal feeding is the more economical, and that it is desirable to stimulate the feed consumption of the fattening animal within reasonable limits. To put the matter in another way, the more rapid production due to heavier feeding, by hastening the completion of the fattening process, shortens the time during which the maintenance ration must be paid for.

It is quite possible, however, that there are limitations to this principle. In the first place, it is obvious that if the feed consumption is stimulated to the point of producing digestive or other disturbances, so that the animal is "off feed," the resulting disturbance and lessened consumption of feed may far outweigh any advantage from the increased amount eaten. It is the regular, uniform eater that is likely to be the profitable animal, rather than the one with a capricious appetite.

But even if this danger be avoided, it is not certain that the maximum possible consumption of feed is the most profitable. Kellner[a] found the digestibility of a mixed ration to decrease somewhat as the amount fed increased. Similar results have also been obtained by Weiske, Kühn, and Jordan, although the result is contrary to current tradition. If this proves to be the case with full feeding in general it is equivalent to a decrease in the metabolizable energy of the feed. Consequently, even though the gain per unit of metabolizable energy might remain the same, the gain per unit of added feed would decrease. Whether, however, the diminution of the percentage digestibility is sufficient to set a limit to the advantage of an increased consumption of feed remains to be shown. Morgen,[a] however, reports experiments on sheep in which very heavy rations actually produced smaller gains in live weight than lighter ones.

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[a] Loc. cit., p. 47.

Finally, it should be remembered that it is the actual gain of potential energy by the animal which we believe to bear a constant relation to the food energy. It has been repeatedly pointed out that the gain in live weight is a very uncertain indication of the amount of energy stored up. It is quite conceivable that the larger gain to be expected on the heavier ration may contain less water and more dry matter, or less protein and more fat, than that produced on the lighter ration, and that consequently the increase in weight may not be proportional to the increase in feed. In that case, unless the higher quality of the gain were recognized in the market, the economic advantage attaching to heavier feeding, as just pointed out, would be diminished or even wiped out.

Varying amount of concentrates.—The general considerations developed in the foregoing paragraph apply directly only to different amounts of the same feed or mixture. In practice these conditions may be obtained with swine, which may be fed exclusively on concentrates, but not with cattle and sheep, requiring a mixed ration of concentrates and fodder. Even with these animals, however, the same general line of reasoning applies to those cases in which the productive part of the rations consists of a concentrate or a mixture of concentrates, the coarse fodder not exceeding the maintenance requirement. The case is the same as that supposed for illustration on page 47. When we come to compare light or medium rations with heavy ones, however, other considerations enter in. Since the coarse fodders are usually relatively cheap, and since ruminants are adapted by nature to consume large quantities of them, a light or medium ration for these animals will usually contain a considerable proportion of roughage. When such an animal is to be put on full feed, physical considerations of bulk forbid the simple increase of both coarse fodder and concentrates in the original proportions, but instead compel a substitution of concentrates for coarse fodder until, in extreme cases, but a minimum of the latter is left and the animal is brought into the abnormal condition of subsisting largely on concentrates.

In the first place, speaking in general terms, a given weight of a concentrate contains more metabolizable energy (fuel value) than the same weight of a coarse fodder, and furthermore, a larger percentage of this larger amount is utilizable in the form of gain. Expressed in more current terms, a pound of concentrates supplies more digestible matter than a pound of coarse fodder, and this digestible matter is more efficient in producing gain.

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[a] Fütterung and Schlachtergebnis, pp. 22 and 33.

In the second place, the substitution enables the animal to consume a greater amount of digestible matter, owing to the smaller bulk of the ration, and this leaves a larger supply over the maintenance requirement to be applied to productive purposes. A steer weighing 1,000 pounds would hardly consume much more than 20 pounds of hay per day, while if the hay were reduced to a minimum of, say, 6 pounds, it would not be difficult to feed with this 16 to 18 pounds of concentrates. On the basis of the figures for timothy hay and corn meal given in Bulletin 71 (revised edition) of the Pennsylvania Experiment Station, page 12, we may make the following comparison of these two rations, assuming as the maintenance requirement 7,350 calories of net available energy. The first column shows the theoretical results on the hay ration, the second those which would be obtained by substituting 14 pounds of corn meal for an equal weight of hay, and the third the effect of further increasing the corn meal.

Comparison of rations composed of timothy hay and of timothy hay and corn meal.

Items.	Ration I, 20 pounds of timothy hay.	Ration II, 6 pounds timothy hay and 14 pounds corn meal.	Ration III, 6 pounds timothy hay and 18 pounds corn meal.
	Calories.	*Calories.*	*Calories.*
Net available energy	9,780	21,250	26,480
Maintenance	7,350	7,350	7,350
Excess over maintenance	2,430	13,900	19,130
Computed gain[a]	1,286	9,529	13,113
Gain per pound of feed	64	476	656
Gain per 100 calories net available energy	13	45	50

[a] Percentage of available energy utilized: For timothy hay 52.93 and for corn meal 68.55.

It is evident that if a calorie of net available energy costs the same in the two feeds there is a great advantage in the substitution of the corn meal for the hay and a further advantage in increasing the amount of corn meal.

The relative cost of grain and hay will, of course, vary from time to time, but as an illustration we may take the prices used by Mumford in Bulletin 83 of the Illinois Experiment Station, viz, $23 per ton for corn meal and $14 per ton for timothy hay. We should then have the following results: Cost of ration per day—Ration I, 14 cents; Ration II, 20.3 cents; Ration III, 24.9 cents. Cost of 1,000 calories gain, respectively, 10.89, 2.13, and 1.90 cents.

On this supposition, taking as the basis of computation the figures on page 12 of Pennsylvania Bulletin 71 (revised edition), if a ton of corn meal is worth $23 for maintenance or production, respectively, a ton of timothy hay would be worth $11.08 for maintenance and $8.55 for production. If, now, we assume the cost of the hay to fall to $7 per ton, that of corn meal remaining unchanged, the energy supplied by the hay, either for maintenance or production, will cost less than that supplied by the corn meal. Nevertheless, when we make the computation, we find that the heavy ration would still give the cheaper gain, the computed cost of 1,000 calories of gain being: Ration I, 5.44 cents; Ration II, 1.91 cents; Ration III, 1.74 cents. That is, even at the relatively high price assumed for corn meal as compared with hay, the large amount of the former which can be consumed gives it the advantage. Even if we assume it possible to feed 30 pounds of hay per day, the cost of 1,000 calories of gain still remains much higher than on the grain rations, viz, 2.71 cents.

Standards.—It is clear from the foregoing that under ordinary conditions mature or nearly mature fattening animals should be fed as heavily and pushed as rapidly as the capacity of the animals and the skill of the feeder will permit. This conclusion was reached long ago by practical feeders, so that the results of experience and of scientific investigation appear quite in harmony. Such an intensive feeding can be effected only by a free use of concentrated feeds, and our computations in the preceding paragraph indicate clearly that, unless concentrates are very expensive as compared with coarse feed, it is economy to substitute the former for the latter to the largest extent possible.

Under these conditions it is evident that there is very little significance in a feeding standard in the ordinary sense, so far at least as the amount of feed is concerned. It may, it is true, serve to afford a basis for preliminary computation of the amount of feed required for a season's feeding, if this is of any importance, but in actual feeding the problem is to induce the animals, by means of the art of the skilled feeder, to consume large amounts of feed without injury to their appetites or digestive capacity, and this is largely a question of the individuality of the animal or lot. The one thing to be kept in mind is to see that the supply of protein in the ration is sufficient to insure the normal growth of protein tissue, since this causes a relatively rapid increase in weight.

GROWTH.

The fattening of mature or nearly mature animals which we have been considering is essentially an improvement in the quality of the meat, and may be characterized as largely a commercial undertaking. As was insisted at the outset, the production of meat in the stricter sense is possible only during growth, and is relatively more rapid the younger the animal. The question of feed requirements for growth is therefore one of prime importance in meat production, and from a general point of view is of equal importance whether the processes of growth and fattening are carried on by one owner or by separate parties.

PROTEIN REQUIREMENTS.

Growth, as we have seen, being largely synonymous with increase of protein tissue, a knowledge of the amount of protein required for normal growth is of the highest importance. As has been pointed out (page 29), however, we are not yet able to formulate any general statement on this point, nor have we any specific experimental data as to the minimum protein requirements at different ages, but must content ourselves with such empirical data as the records of successful feeding experiments afford.

Protein requirements of cattle.—The experiments tabulated earlier in discussing the rate of growth include three series of experiments upon young calves, viz, those of Soxhlet, DeVries Jzn, and Neumann, the feed being whole milk in the first case and skim milk in the last, while De Vries Jzn's experiments include both, in some cases with the addition of starch to the skim milk.

We may perhaps assume that the amount of whole milk consumed by the calf gives an approximate measure of its requirements. The natural conclusion from this would be that the skim-milk calves tended to receive an excess of protein. Computing the results per 1,000 pounds live weight and grouping by ages we have the following summary:

Protein supply and protein gain of calves.

Authority.	Animal.	Period.	Age.	Digestible protein per 1,000 pounds live weight.	Gain of protein per 1,000 pounds live weight.
			Days.	*Pounds.*	*Pounds.*
Soxhlet	A	I	18	4.24	2.80
	A	II	32	4.29	2.71
	B	I	15	5.50	3.55
	B	II	21	4.77	3.02
	C	I	8	5.71	3.99
	Average		19	4.90	3.22
De Vries Jzn	B	I	38	4.93	2.12
	C	I	37	5.61	2.28
	D	I	45	3.48	2.17
	Average		40	4.67	2.19
	A	I	50	5.21	1.50
	A	II	65	4.48	1.72
	A	III	74	4.26	1.27
	C	II	64	4.37	1.21
	D	II	63	2.84	1.21
	D	III	74	2.79	1.27
	Average		65	3.99	1.36
	A	IV	100	3.32	1.19
Neumann	First series	I	40	6.30	2.95
		II	45	5.94	2.42
	Second series	I	57	5.70	2.28
		II	62	5.36	1.61
		IV	69	5.28	1.82
	Average		55	5.72	2.22

Neumann used skim milk exclusively, giving somewhat heavier rations than in the other cases, but did not obtain a materially greater gain of protein by the animals than did the other experimenters, if we except the second group of the experiments by De Vries Jzn.

On older cattle we have the following results of Jordan's experiments. The data given are those reported for animals Nos. 2 and 3.

Protein consumed by cattle.

Period.	Average age.	Digestible protein per 1,000 pounds live weight.
		Pounds.
First fifteen months:		
Steer No. 2	About 15 months	1.65
Steer No. 3	do	1.12
Last twelve months:		
Steer No. 2	About 28 months	1.68
Steer No. 3	do	.95

Steer No. 2 gained weight more rapidly than steer No. 3 during the first fifteen months, but the reverse was the case during the last twelve months.

To the foregoing results the general averages estimated in the paragraphs on fattening may be added, and we have the following as the amounts of protein which have been supplied to cattle at different ages with apparently satisfactory results:

Amounts of protein supplied to cattle by various experimenters.

Age.	Experimenter.	Digestible protein per 1,000 pounds live weight.
		Pounds.
19 days	Soxhlet	4.90
40 days	De Vries Jzn	4.67
55 days	Neumann	5.72
65 days	De Vries Jzn	3.99
100 days	do	3.32
1 year	Waters	2.00
1½ years	Schneidewind	2.00
2 years	do	1.50–1.75
2 years	Waters	>1.50
2½ years	Jordan and Frear	>1.33
2½ years	Mumford	>1.50
6–7 years	Kellner	.75–1.00

While these figures must be interpreted in a very broad way, they show clearly a decreasing protein requirement per 1,000 pounds weight with advancing maturity.

The results tabulated above have been platted graphically on figure 1, being represented by the sign **x**, while the upper curve of the diagram represents the Wolff-Lehmann standards on the same scale.

It is hardly a mere coincidence that when thus platted the above results give a curve quite similar to that previously found as representing the rate of growth. Furthermore, it is of considerable interest to find that these results, worked out independently, and to a considerable extent from American data, correspond quite closely with the Wolff-Lehmann standards for growing beef cattle, as appears from a comparison of the figures and from the corresponding curve in the diagram.

Protein requirements of sheep.—But few satisfactory data regarding the protein requirements of sheep appear to be available. A certain amount of protein is of course required for the growth of the wool. On the basis of a number of results by Henneberg and his associates, this may be estimated at about 0.15 pound of protein per 1,000 pounds live weight per day. While this, although small in itself, is considerably greater than the accepted estimates for the growth of hair in cattle, yet it is hardly sufficient to justify the somewhat current notion that sheep require a considerably greater protein supply than cattle.

Wolff based his standards for growing sheep largely upon experiments of his own.[a] Somewhat later the experiments by Weiske[b] on the growth of lambs, which have been cited on previous pages, afforded confirmation of Wolff's results. Wolff's experiments included only determinations of the digestibility of the rations and the gain in live weight; Weiske's included also determinations of the nitrogen balance, which showed an apparently normal rate of growth. The following are the amounts of digestible protein per 1,000 pounds live weight consumed in the two series of experiments, the results being arranged in order of age:

Protein consumed by sheep.

Age.	Digestible protein per 1,000 pounds live weight.	Experimenter.
	Pounds.	
4 to 5 months	3.76	Weiske.
5 to 6 months	3.26	Do.
5 to 6 months	3.16	Wolff.
6 to 7 months	2.78	Weiske.
6 to 8 months	2.96	Wolff.
7 to 9 months	2.76	Weiske.
8 to 9 months	[c]1.87	Wolff.
9 to 10 months	2.38	Weiske.
10 to 11 months	2.30	Do.
9 to 12 months	[c]1.38	Wolff.
11 to 12 months	2.16	Weiske.
12 to 14 months	1.96	Do.
12 to 14 months	1.61	Wolff.
14 to 15 months	1.92	Weiske.
24 months	1.22	Do.

Apparently the amount of protein fed in the above experiments was ample, but there is nothing to show whether smaller amounts would have been equally sufficient or not, the inferior growth observed by Wolff in two cases being attributable, in part at least, to a deficient amount of total feed.

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[a] Landwirtschaftliche Jahrbücher, bd. 2, p. 221. Compare also Armsby, Manual of Cattle-Feeding, pp. 448–451.

[b] Landwirtschaftliche Jahrbücher, bd. 9, p. 205.

[c] Believed by the author to be too low, owing to the inferior quality of the hay fed and consequent small amount eaten.

In the other experiments with lambs and sheep referred to on previous pages, considerably larger amounts of protein were fed, so that no indications are to be derived from them as to the lower limit of protein supply. The writer has not yet been able to compile the data of American experiments bearing on this point.

Protein requirements of swine.—The experiments by Sanford and Lusk and by Wilson on sucking pigs afford an instructive example of the capacity of young animals to consume and utilize protein. On the average of these experiments the amounts of protein consumed daily, computed per 1,000 pounds live weight, and the amounts retained in the body were as follows:

Protein supply and protein gain of pigs.

Experimenter.	Average age.	Protein digested per 1,000 pounds live weight.	Protein stored in body per 1,000 pounds live weight.
	Days.	*Pounds.*	*Pounds.*
Sanford and Lusk	7	13.68	5.86
Wilson	8	14.71	5.93

Considerable emphasis has been laid upon the necessity of a liberal protein supply for the pig in view of his rapid growth. A large number of experiments, for example, are cited by Wolff, in his classic compilation,[a] showing the much greater feed economy incident to the use of rations with a narrow nutritive ratio for young pigs. Altogether similar results were reached in a compilation[b] of American pig-feeding experiments prepared by the writer for the United States Department of Agriculture.

The well-known experiments by Sanborn, Henry, and others upon the influence of extreme rations on the proportion of fat and lean in the carcass are too familiar to need repetition here. They have served to call attention sharply to the need for protein in the feed of young pigs, but because the experimental conditions were purposely made extreme it seems possible that they have given rise to exaggerated notions regarding the actual amount of protein required and the effect of practicable variations in rations. Some of the more recent experiments of this class, at any rate, tend to throw doubt upon the validity of the very high protein requirements for pigs formulated in the Wolff-Lehmann standards.

Attention may be called particularly to some comparatively recent experiments at the Wisconsin and Iowa experiment stations upon the influence of wide and narrow nutritive ratios upon the character of the carcass. Some of the main results of the Wisconsin experiments are tabulated below.

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[a] Die Ernährung der Landwirtschaftlichen Nutzthiere, pp. 465–496.

[b] Unpublished manuscript.

Influence of protein supply on growth of pigs.

	Number of animals.	Length of experiment.	Average age at beginning.	Average weight at beginning.	Average weight at middle of experiment.	Digestible protein per day per 1,000 pounds live weight.	Total nutrients per day per 1,000 pounds live weight.	Average gain.	
								Per head.	Per 1,000 pounds live weight.
		Days.	*Days.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Seventeenth Report, page 12:									
Lot 1	8	126	65	65	143.4	2.54	24.17	1.24	8.670
Lot 2	8	126	65	65	139	5.07	23.11	1.17	8.425
Eighteenth Report, page 25:									
Lot 1	5	84	184	133.2	173.6	2.72	25.12	.96	5.55
Lot 2	5	84	182	133.6	157.8	3.81	19.57	.58	3.65
Eighteenth Report, page 44:									
Lot 1	5	210	118	48.1	119.6	4.72	19.67	.75	6.27
Lot 2	5	210	116	47.1	106	2.29	24.42	.63	5.94
Nineteenth Report, page 17:									
Lot 1	6	144	125	68.4	128.7	5.40	22.57	.837	6.504
Lot 2	7	144	128	68.4	120.4	1.90	22.70	.540	4.485
Twenty-first Report, page 25:									
Lot 1	3	110	(?)	52.3	74	2.97	31.70	.394	5.32
Lot 2	3	110	(?)	53.7	114	3.52	25.31	1.097	9.62
Twenty-first Report, page 32:									
Lot 1	3	98	240	225	287	3.55	19.81	1.262	4.40
Lot 2	3	98	240	213	267	2.19	19.90	1.099	4.12

The data of the block tests which were made in each case afford data for the following notes:

Seventeenth Report, page 12.—The carcasses of lot 1 (wide ration) showed the greater thickness of fat in back and shoulders and more kidney fat, while those of lot 2 showed greater weight of blood and internal organs.

Eighteenth Report, page 25.—Lot 1 (wide ration) dressed a higher percentage than lot 2, but there is no definite indication of higher percentage of adipose tissue. Photographs seem to show greater development of loin muscles in lot 2.

Eighteenth Report, page 44.—Photographs of the loin cuts seem to indicate much greater proportion of fat to lean in lot 2 (wide ration), but computed per 1,000 pounds live weight the amounts of internal organs and internal fat do not differ widely.

Nineteenth Report, page 17.—After the first six weeks the peas (lot 1) were relished better and eaten more freely than the corn. The carcasses of lot 1 were flabby with thicker outside fat and somewhat more internal fat.

Twenty-first Report, page 25.—The pigs of lot 1 were stunted, and on slaughtering large numbers of worms were found in the intestines. There is no proof of difference in relative development of lean meat and fat.

The experiments reported by the Iowa station[a] include two trials of "wide" versus "narrow" rations. In both cases the "wide" lot gained somewhat more per day and per pound of dry matter in the feed. In the first trial the "wide" lot ate somewhat more dry matter than the other; in the second trial this particular is not stated. In neither case were the differences very marked. It seems safe, therefore, to compare simply the computed protein supply (digestible) in the two cases, using the figures in Farmers' Bulletin 22 (revised) as the basis.

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[a] Iowa Experiment Station, Bulletin 48, pp. 373–451.

Comparison of rations of high and low protein content fed to hogs.

	Second experiment.		Third experiment.	
	High protein.	Low protein.	High protein.	Low protein.
Animals....number..	5	5	5	5
Length of experiment....days..	153	153	163	163
Average age at beginning....do....	54	51	52	52
Average weight at beginning....pounds..	35.0	38.0	22.0	22.0
Average weight at middle of experiment....do....	130.8	143.6	96.8	102.3
Digestible protein per day:				
Per head....do....	.737	.431	.667	.462
Per 1,000 pounds weight....do....	5.630	3.0	6.890	4.520
Average gain per day:				
Per head....do....	1.26	1.38	.91	.98
Per 1,000 pounds weight....do....	9.63	9.61	9.40	9.58

In the second experiment Swift & Co. valued the cuts as follows: High-protein lot, $6.40; low-protein lot, $7.13. The low-protein lot showed the largest percentage of dressed weight (79 as against 77.1), but was regarded as too fat, especially for the English market.

A representative animal of each lot was analyzed by the United States Department of Agriculture, the head, and the kidney and leaf lard not being included.

Calculated on dry matter, the composition of the carcasses was as follows:

Composition of carcasses of hogs fed on rations with high and low protein content.

Constituents.	High protein.	Low protein.
	Per cent.	*Per cent.*
Fat....	81.38	81.52
Total protein....	13.28	14.06
Ash....	2.97	2.51
Lecithin....	.16	.27
	97.79	98.36

The percentage of fat in the dry matter of the more important cuts was as follows:

Percentage of fat in the dry matter of different cuts of hog carcasses.

Cut.	High protein.	Low protein.
	Per cent.	*Per cent.*
Backs....	92.43	92.41
Bellies....	88.66	90.06
Hams....	72.54	62.32
Shoulders....	96.24	79.92
Spareribs....	58.59	63.70
Tenderloins....	34.11	40.98

Only in the case of the spareribs and tenderloins does the low-protein lot show any excess of fat, and even if we take the percentages calculated upon the fresh substance we add to this list only the hams. If the carcasses analyzed were representative, it would seem that the judgment of the market is based rather upon the distribution of the fat in the carcass than upon its total amount. In the third experiment the low-protein lot again dressed the highest percentage, but no definite statements appear as to the quality of the carcasses. It should be noted that in these experiments, as contrasted with those of the Wisconsin station, a considerable variety of feeds was given to each lot.

While the few experiments which have been cited are an entirely insufficient basis on which to formulate the protein requirements of pigs, it is evident that the very large amounts of protein consumed in some of these experiments were of no advantage so far as gain in live weight was concerned, and of questionable effect upon the make-up of the carcass. Making liberal allowance for the approximate nature of the data, it would seem that the following amounts of digestible protein per day per 1,000 pounds live weight were fairly sufficient for growing pigs:

	Pounds.
2 months old	3.00
4 months old	2.75
6 months old	2.50
8 months old	2.25

Further investigations and a systematic compilation of existing data are, however, greatly to be desired.

TOTAL FEED.

The same general principles which have been discussed in considering the total feed requirements of mature or nearly mature fattening animals may be safely assumed to apply also to younger animals, but their application is essentially modified by the fact that we can not greatly stimulate the growth of young animals by heavy feeding.

"*Stockers.*"—As already noted, a large share of our meat supply is derived from animals reared until nearly mature and marketed as "stockers" to be finished by other parties, or, if older and of inferior quality, to swell the supply of canned meats and the like. Animals of this class are largely produced on cheap feed, grown on relatively cheap or rough land, generally under pasturage or range conditions. So long as large areas of cheap grazing land are available, as in the West and Southwest of the United States, it will be cheaper to ship the nearly mature animals destined for fattening to the feed than to ship the feed to the animals or to raise it in the locality, particularly at points distant from the great centers of consumption.

Under these conditions there is little call for anything in the nature of a feeding standard. The young animal runs with the dam until naturally weaned. The ordinary pasture or range plants are likely to be fairly rich in protein, and if the total supply is sufficient a normal rate of growth is assured. Whether the supply of feed shall be derived entirely from the natural growth, or whether this shall be supplemented by the growth of forage for winter feeding, is an economic question, to be decided according to local conditions.

Fat animals.—The production of "stockers" is not, of course, necessarily confined to the range; but at the same time, whenever any considerable expenditure is necessary for shelter and the growth of feeding crops, it becomes important to consider whether it may not be more profitable to finish the animals and market them in condition for the butcher. As has been shown, the rate of growth is largely a function of the individuality of the animal, and so far as the production of actual meat is concerned we are obliged to wait on the processes of nature. An attempt to force the animal prematurely by heavy feeding can result only in an overproduction of fat before the animal is of sufficient size to market, or before it has developed sufficient lean meat to yield a high-grade carcass. Fattening is relatively a more rapid process than growth in the sense that a sufficient amount of it to insure a high market quality of the meat may be accomplished in a much shorter time than is required for the growth of that meat.

The practical conclusion from these well-established facts is sufficiently obvious.

With any given type of animal, the age at which it will reach marketable form and size is fixed by the individuality of the animal, and so far as appears can be but slightly, if at all, hastened by the feeding. The earlier this point is reached the less, other things being equal, will be the feed cost of producing the animal; and on the other hand, the longer the animal is kept after that point is reached the less will be the profit to the owner.

In order that the animal shall be marketable for slaughter at that age, however, it must not only have produced the due amount of meat, but that meat must have the quality which is imparted by the fattening process. With this in view, we shall naturally aim to begin the feeding of fattening rations at such a point of time that when the actual growth of meat becomes so slow as to be no longer profitable the fattening process will also be completed. Too early a commencement of the fattening process will lead to waste in several ways. If the animals are pushed they become ripe before the possibilities of profitable growth are exhausted, and must either be marketed or else held at considerable expense until the growth can overtake the fattening. Moreover, it seems not improbable that too early fattening may actually be prejudicial to the production of lean meat, offering actual mechanical hindrances to its growth. If in the effort to avoid these drawbacks light feeding is resorted to, the period of time during which special care must be given to the feeding is unnecessarily prolonged. Beginning fattening too late unnecessarily extends the period during which the animal must be maintained and cared for without any compensating advantage, since the same gain of fat could have been secured earlier at no greater expense. Just when the fattening should begin will obviously depend upon the kind and individuality of the animal and upon the degree of fattening which the demands of the market and the cost of feed render desirable. The more rapid the rate of growth of the animal and the earlier it may be expected to reach maturity, the further back toward birth is the beginning of the fattening pushed, so that with small, quick-growing animals, like pigs, feeding and fattening may become almost synonymous.

It is not the present purpose of the writer to attempt to formulate numerically the total feed requirements of growing animals. Indeed he is inclined to question whether such standards, however accurate they may be made and however great their statistical value, can ever play any large part in practical feeding operations. Given a knowledge of the protein requirements, and of the means by which they may be satisfied, it may be questioned whether the observation of the skilled feeder, supplemented by occasional weighings, will not afford more satisfactory results than attempted adherence to a standard ration.

MANAGEMENT.

While the practical methods of management in stock feeding are outside the scope of a paper on feeding, nevertheless they have an important bearing upon the actual results obtained, and some discussion of the general principles involved may properly find a place here.

MUSCULAR EXERTION.

The well-known fact that muscular exertion is accomplished at the expense of the metabolism of tissue, and ultimately, therefore, at the expense of the feed, would seem at first thought to indicate that the activity of the meat-producing animal should be restricted as much as practicable. In the case of the growing animal, however, another very important element enters into the case, namely, the fact that moderate exercise tends to stimulate the growth of the muscular system, or, in other words, the production of lean meat. Since this is the essential object sought, a normal and reasonable amount of muscular activity on the part of the growing animal should be allowed and encouraged, even though the muscular exercise involves the consumption of more feed. Accordingly, young stock should be given the freedom of the pasture or range to as great an extent as practicable, while at the same time care should be taken to supply abundant feed containing a sufficient supply of protein, in order that sufficient material may be present to supply the demand for growth stimulated by the exercise.

In the case of breeding stock especially, a most important consideration is that of the health and stamina of the animal, which can hardly fail to suffer through overconfinement. The above principles apply in a general way to all classes of stock. In particular, hogs should be given an opportunity for more movement and exercise than is frequently allowed.

In the case of animals which have reached the fattening stage, on the other hand, there is comparatively little growth of protein tissue, while we only need to maintain sufficient health to insure a normal appetite and assimilation of food. In proportion, then, as this stage is reached we should endeavor to reduce the amount of exercise taken and to keep the fattening animal as quiet as possible. To this end comfortable quarters should be provided, with plentiful bedding, and the animals should be kept as undisturbed as possible, so that they may "eat and lie down." Results of experiments at the Pennsylvania station have shown an increase of 30 to 40 per cent in the metabolism of the same steer standing as compared with lying down. This is particularly important in the case of the sheep on account of its timid nature. For similar reasons it is desirable to have the water supply of fattening animals close at hand.

WATER SUPPLY.

It should never be forgotten that rapid production, involving the utilization of relatively large amounts of feed, requires the consumption of a corresponding amount of water for the physiological purposes of the animal. For this reason, as well as for the one mentioned above, it is desirable that stock should have ready access to water, if possible, at all times. Furthermore, the water supplied should not be too cold to be consumed freely by the animals.

SHELTER.

From the physiological point of view, considerable emphasis has been laid in the past upon the economic importance of providing fairly warm quarters for live stock in order to avoid a wasteful oxidation of the food for simple heat production. At the same time, however, vast numbers of cattle were being successfully fattened in sheds and open feed lots, and more recently the results both of physiological investigation and of practical experiments have led to considerable modification of the views formerly held. In the aggregate a considerable amount of experimental work is on record, of which the following is a condensed summary:

EXPERIMENTAL RESULTS.

Cattle.—Patrick and Smith,[a] as part of an experiment on the winter fattening of steers, compared two 3-year-old steers fed in a yard provided with an open shed with two others fed in the barn. Both pairs gave similar gains in a first period of twenty-four days on approximately like rations of corn-and-cob meal and corn fodder in the barn. Steers Nos. 5 and 7 were then transferred to the yard and the feed was changed to shelled corn and corn fodder, which was continued for thirty-seven days, results for the last thirty-one days (February 1–March 3) being reported. The dry matter eaten per pound of gain in live weight by the two lots and also by a comparison lot in the barn on unchanged feed was as follows:

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[a] Iowa Experiment Station, Bulletin 6, p. 205.

Comparison of results of steer feeding with and without shelter.

Steers.	Period I.		Period II.	
	Feed.	Dry matter per pound of gain.	Feed.	Dry matter per pound of gain.
		Pounds.		*Pounds.*
Nos. 4 and 8 (comparison lot).	Corn-and-cob meal and corn fodder, in barn.	6.86	Corn-and-cob meal and corn fodder, in barn.	15.72
Nos. 6 and 9	do	7.44	Shelled corn and corn fodder, in barn.	11.84
Nos. 5 and 7	do	6.82	Shelled corn and corn fodder, in yard.	13.61

The lot fed in the yard ate much more corn and less fodder than the comparison lot in the barn. On their face the results appear to favor the indoor feeding, but the differences are not large, and in view of the small number of animals and of the short period following a change of feed their value may be questioned. The winter is said to have been an unusually mild one. The authors note (loc. cit., p. 237) that sudden changes of temperature affected the gains unfavorably both in the shed and in the barn.

Gulley[a] obtained much inferior results with six Texas range steers fed in an open lot as compared with six others dehorned and fed in an open shed, but it is not clear how far the greater quietness caused by dehorning affected the results.

Georgeson[b] fed two lots of five three-year-old grade Shorthorn steers on ear corn, corn stover, and prairie hay for six months, one lot being tied in the barn and the other loose in a yard provided with an open shed. The difference in mean weekly temperature between barn and shed ranged from 2.7° F. in May to 35.5° in January, but was not less than 11.3° during the winter months. The lot in the yard ate more grain and hay than the one in the barn. The weather is stated to have been generally dry and clear and favorable to outdoor feeding. The lowest weekly mean reported is 6.1° F. in January. The feed consumption per pound of gain was as follows:

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[a] Texas Experiment Station, Bulletin 6.

[b] Kansas Experiment Station, Bulletin 34.

Consumption of feed per pound of gain by steers confined in barn and loose in yard.

Place.	Ear corn.	Corn stover.	Prairie hay.
	Pounds.	*Pounds.*	*Pounds.*
In barn	14.17	2.93	1.79
In yard	15.57	2.90	2.15

Sanborn [a] fed two lots of steers, one in the barn and one in the open air, from December 27 to April 20, reversing the lots on February 12. The grain ration was the same in each case, but the cattle out of doors ate their coarse fodder more completely.

Results of steer feeding in barn and in open air at the Missouri Experiment Station.

Place.	Feed consumed.		Gain.
	Grain.	Coarse fodder and silage.	
	Pounds.	*Pounds.*	*Pounds.*
In barn	2,736	4,202	381
In open air	2,736	5,209	374

The average temperature during February was 48° F. in the barn and 26° F. in the open air, the weather being dry.

Sanborn [b] in 1890-91 found that three steers fed in a yard protected from winds, but with no shed, ate more coarse feed and made greater gains, both absolutely and per unit of feed, than three comparison lots fed in the barn. The data cover the time from January 15 to April 1, and the weather is stated to have been dry and quiet with moderate temperature, the lowest being 12° F. and the average 23.4° F. It is thought that the greater opportunity for exercise in the yard accounted in part for the greater feed consumption and consequent greater gain. In the following year [c] the exposed lot on limited feed gained as much as the lot tied in the barn, but less than one in a box stall. When fed ad libitum, however, the exposed lot made a notably greater gain than either lot in the barn with no greater relative consumption of feed. The winter was "an average one in temperature with unusual snowfall and frequent spring rains." In the next year [d] a lot in an open yard and one in an open shed each ate more feed than one in a box stall in the barn when both were fed all they would eat. The total gains and the gains per unit of feed were greater in the box stall and least in the shed. If, however, the gains for the preliminary period be included, but little difference appears in the gain per unit of feed. The winter was an average one. The average temperature of the barn was 43.1° F. and that of the yard and shed 28.1° F.

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[a] Synopsis of experiment at the Missouri Experiment Station, p. 1.

[b] Utah Experiment Station, Bulletin 11.

[c] Utah Experiment Station, Report for 1892, pp. 21-25.

[d] Utah Experiment Station, Bulletin 23.

Thorne and Hickman[a] fed two 3-year-old steers in the barn and a similar lot in an open shed in 1894 and 1895. The average results for the two lots are reported as follows:

Results of steer feeding in barn and in open shed at the Ohio Experiment Station.

Place.	Daily gain per head.	Dry matter of feed per pound of gain.
	Pounds.	*Pounds.*
In barn	1.99	10.20
In shed	1.93	10.53

Shaw[b] fed seven steers, past 2 years old, tied in the barn, as compared with the same number in an inclosed shed open on a yard, for one hundred and forty days, with the following average results per day and head:

Results of steer feeding in barn and in shed at the Minnesota Experiment Station.

Place.	Feed consumed.		Gain.	Total feed per pound of gain.
	Hay.	Grain.		
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
In barn	11.31	13.36	1.74	14.18
In shed	10.74	16.21	2.26	11.92

Waters[c] reports four similar trials with fattening steers, each covering over one hundred days with four or five steers in each lot. One lot in each case was fed in a moderately tight barn but turned out for eight hours on pleasant days, one lot was fed in an open shed, and a third lot in an open lot. The daily results per head were as follows:

Average daily results of feeding steers with different degrees of protection at the Missouri Experiment Station.

Year and place.	Feed consumed.		Daily gain.	Total feed per pound of gain.
	Hay.	Corn.		
1897-98.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
In barn	8.57	18.35	1.47	18.31
In shed	9.52	19.89	1.72	17.10
1898-99.				
In barn	10.09	19.57	1.85	16.03
In shed	8.07	21.53	2.30	12.87
In open lot	10.09	19.57	2.29	12.95
1899-1900.				
In barn	7.00	19.00	1.67	15.93
In shed	8.00	19.46	1.69	16.25
In open lot	7.00	18.62	1.78	14.39
1900-1901.				
In barn	5.20	19.96	1.83	13.75
In shed	6.29	21.76	1.97	14.24
In open lot	8.81	24.26	2.09	15.82

Waters also reports that, in response to a letter of inquiry, out of 663 feeders of beef cattle in Missouri, Illinois, Iowa, and Nebraska,

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[a] Ohio Experiment Station, Bulletin 60, p. 24.

[b] Minnesota Experiment Station, Bulletin 76, p. 250.

[c] Monthly Bulletin, Missouri Board of Agriculture, September, 1901, p. 23.

546, or over 83 per cent, preferred to feed in an open shed or lot rather than in the barn, and that the "barn" described by many of the remaining 117 was little more than a large open shed.

Waters calls attention to the fact that the above results were all upon cattle on full feed and that they do not apply to young thin animals or breeding cattle, and states that four years' experiments on yearlings have given decisive results in favor of barn feeding.

Mairs[a] compared feeding in a warm barn with that in an open shed for four consecutive winters with lots of 12 steers each, the feeding covering from eighty-four to one hundred and twenty-six days. The total feed (grain and coarse fodder) consumed per pound of gain in the four experiments was:

Total feed consumed per pound of gain by steers at the Pennsylvania Experiment Station.

Year.	In barn.	In shed.
	Pounds.	*Pounds.*
1902-3	13.40	14.60
1903-4	13.81	15.32
1904-5	18.67	18.42
1905-6	16.07	15.80

These experiments differ from some of those noted above in the fact that the grain ration eaten by the two lots was nearly the same and that slightly less coarse fodder was eaten in the shed than in the barn. It was practically a test of equal rations under the two conditions. Mairs was unable to trace any connection between the temperature record and the rate of gain, and is inclined to ascribe the poorer results in the shed for the first two years to uncomfortable quarters.

While the foregoing results are more or less divergent, it is worthy of note that the experiments covering a full fattening period, with one exception (Georgeson), show fully as good results for the exposed as for the barn-fed animals. It seems clear at least that the value of shelter for fattening cattle has been exaggerated.

Sheep.—Sanborn[b] fed one lot of long-wooled sheep in the barn and a comparison lot in the open air from December 4 to May 10, with the following results:

Results in sheep feeding in barn and in open air at the Utah Experiment Station.

Items.	In barn.	In open air.
Preliminary, fourteen days:	*Pounds.*	*Pounds.*
Gain	18	19
Feed eaten	143	168
Feed per pound of gain	7.94	8.84
First period, thirty-five days:		
Gain	12	19
Feed eaten	265	278
Feed per pound of gain	22.08	14.63
Second period, one hundred and five days:		
Gain for first sixty-two days	45	36
Total gain	26	0

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[a] Pennsylvania Experiment Station, Bulletins 64, 68, 74, and 83.

[b] Utah Experiment Station, Report for 1892, p. 25.

During the last month both lots lost weight, but the feed consumption is given for the whole period only. This loss is ascribed to the moister storms of the late winter and early spring.

The same author reports briefly[a] the results of a second comparison with lambs, covering four weeks, in which the greater gain was made by the lot in the barn at an average temperature of 43° F., compared with a lot in an open shed at 28° F. The author believes that wet weather affects sheep more injuriously than cattle on account of the long time required for the wool to dry.

In an experiment on fattening lambs Shaw[b] fed similar rations to three lots of eight 6-months-old lambs each, one in an open yard, one in a shed open to a yard, and one in the barn. The following results are reported per day and head:

Experiments in sheep feeding at the Minnesota Experiment Station.

Lot.	Total feed eaten.	Gain.	Feed per pound of gain.	Cost per pound of gain.
	Pounds.	*Pounds.*	*Pounds.*	*Cents.*
Lot 1, yard	2.96	0.280	10.58	5.36
Lot 2, shed	3.18	.321	9.96	4.71
Lot 3, barn	3.09	.284	10.87	5.41

F. B. Mumford[c] fed two lots of 10 lambs each, averaging about 85 pounds live weight, one being confined in a well-ventilated (and apparently cold) barn, while the other was fed in similar quarters but with the run of an open yard, where they were frequently exposed to rain and snow. The results for thirteen weeks were:

Experiments in sheep feeding at the Michigan Experiment Station.

Lot.	Total feed eaten.			Gain.	Dry matter per pound of gain.
	Grain.	Hay.	Dry matter.		
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Lot 1, outdoor	1,196	1,087	1,978	205	9.65
Lot 2, indoor	1,164	1,173	2,019	230	8.77

Middleton[d] compared feeding sheep in an open shed and out of doors on similar rations. The average daily gain per head was: In the shed, 0.168 pound; out of doors, 0.189 pound.

On the whole such scanty data as are available seem to indicate that sheep do not stand exposure, especially to rain and snow, as well as cattle, and that shelter from storms is a not unimportant factor in mutton production.

Swine.—But few experiments with swine bearing on the subject under discussion are on record.

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[a] Utah Experiment Station, Bulletin 23, p. 7.

[b] Minnesota Experiment Station, Bulletin 44, p. 280.

[c] Michigan Experiment Station, Bulletin 128.

[b] Experiment Station Record, vol. 15, p. 897.

Shelton[a] fed five yearling swine in a warm barn in comparison with five similar animals in an open yard without shelter, the feed being shelled corn in both cases. The results for the ten weeks of the experiment were:

Results of pig feeding, with and without shelter.

Items.	Sheltered.	Exposed.
Average temperature..........° F..	29.9	15.8
Total feed..........pounds..	2,878	2,844
Total gain..........do....	604	[b] 489
Feed per pound of gain..........do....	4.76	[b] 5.82

Two of the animals in the exposed lot made practically the same gain as the average of the sheltered lot, although one of the two also ate decidedly more feed. The following comparison of the periods of highest and lowest temperatures is also of interest:

Comparison of the effects of high and low temperature during hog-feeding experiments.

Items.	Highest temperature.		Lowest temperature.	
	Sheltered.	Exposed.	Sheltered.	Exposed.
Average temperature..........° F..	37.3	26.3	22.3	2.5
Total feed..........pounds..	1,184	1,245	1,087	997
Total gain..........do....	301	[c] 260	190	88
Feed per pound of gain..........do....	3.93	[c] 4.79	5.71	11.43

Compared in this way, the effect of the shelter during the severe weather is very marked. The gain of the exposed animals during these weeks were very irregular and frequently negative.

Sanborn[d] fed two lots of shoats, one in an open shed and one in the basement of a warm barn, reversing the lots at the end of forty-two days and continuing the experiment for seventy days more. The totals per head for the entire experiment were:

Results of pig feeding in barn and in open shed at the Missouri Experiment Station.

Place.	Feed.		Gain.
	Corn meal.	Skim milk.	
	Pounds.	*Pounds.*	*Pounds.*
In barn..........	463.5	18	83.9
In shed..........	463.5	18	74.8

The same author[e] obtained the following results in a later experiment of the same sort, covering one hundred and thirty-six days from December 9.

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[a] Kansas State Agricultural College, Report of Professor of Agriculture, 1883, p. 1.

[b] Figures differ from those reported by the author.

[c] Figures differ from those computed by the author.

[d] Synopsis of experiments at the Missouri Experiment Station, p. 4.

[e] Utah Experiment Station, Bulletin 23, p. 4.

Results of pig feeding at Utah Experiment Station.

Place.	Grain consumed.	Total gain.	Feed per pound of gain.
	Pounds.	*Pounds.*	*Pounds.*
In barn	1,432	237	6.04
In shed	1,702	254	6.70

Friis[a] notes that the alleged effect of maize and of sunflower cake in producing soft pork is more marked in cold weather.

GENERAL PRINCIPLES REGARDING SHELTER.

The foregoing results, while indicating that the requirements of meat-producing animals for shelter may have been overestimated, nevertheless render it clear that the question is one of adaptation to conditions and that no invariable rule can be laid down. It may be profitable, therefore, to turn to a consideration of the scientific principles involved.

Temperature.—As the writer[b] has pointed out in discussing the energy relations of the feed and the animal, there is a certain approximate temperature, called the critical temperature, at which the minimum outflow of heat just balances the necessary heat production as a result of the internal work, and below which more or less oxidation of tissue is required to maintain the normal temperature of the body. Furthermore, it has been shown that the digestion and assimilation of the feed and its conversion into tissue result in the evolution of relatively large amounts of heat, especially in the ruminants, and that the effect of this internal production of heat is virtually to lower the critical temperature as compared with that of the fasting animal. In other words, there is for each animal and for each ration a certain temperature above which the heat produced becomes in part an excretum, to be gotten rid of by radiation and evaporation.

It appears likely that a certain excess of heat production over that absolutely required to maintain the body temperature is advantageous, both as promoting the comfort of the animal and especially as affording a margin in case of temporary fluctuations of temperature. On the other hand, both our own personal sensations and the observations of practical stock feeders show that an unnecessarily high temperature is debilitating, affecting both appetite and general health. In practice, then, we should endeavor to keep the thermal surroundings of the animal within the range above indicated—somewhat above the critical point but not so much so as to affect appetite and thrift. It is evident that the limits of this range may vary widely with the kind of animal and with the character of the ration.

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[a] Experiment Station Record, vol. 11, p. 70.

[b] Principles of Animal Nutrition, pp. 353–359 and 432–438.

Amount and character of ration.—The influence of this factor upon the requirements for shelter is clearly indicated by what has already been said. The heavier the ration, other things being equal, the more heat will be evolved during its digestion and conversion into tissue, while with equal amounts of feed those materials which require the greatest expenditure of energy for digestion and assimilation will be the most abundant source of heat. Since, however, these are in general the bulky coarse fodders, the amount of them which can be consumed is limited and the heavier grain rations are practically those which supply the animal with the greatest surplus of heat. Mature animals on full feed thus have at their disposal a large amount of surplus heat and naturally can thrive under conditions of exposure which might be seriously detrimental to young, growing animals on relatively light rations. Thus one of Kellner's experiments (Ox E, Period III) gave the following results:

Fuel value of ration	calories	26,660
Energy stored as gain	do	5,920
Energy evolved as heat	do	20,740
Computed maintenance requirement	do	15,060
Excess of heat	do	5,680
Excess over maintenance	per cent	37.7

Age and weight of animals.—The internal work of like animals of different sizes, under like conditions, appears to be approximately proportional to their body surface, and there is even good ground for believing that this law applies to a large extent to animals of even the most diverse species and size. Since the action of external temperature is also approximately proportional to the surface, we should expect that the size of the animal would not be an important factor. In fact, however, the other conditions are rarely alike. The young animal in particular is likely to be getting a relatively lighter ration than the animal which is being pushed for the butcher, and thus to have less surplus heat at its disposal. Furthermore, while there appear to be no measurements on record of the relative surfaces of young and of mature animals, common observation would seem to indicate that it is relatively greater in the young animal. Finally, the indefinable factor of "hardiness" would seem to be in favor of the older animal.

Humidity.—The relative humidity of the air is an important factor in the temperature relations of the animal. Moist air tends to increase the conductivity of the hair or wool and thus in effect to raise the critical temperature. Accordingly, we should anticipate that in a dry climate, like that of the Northwest, animals might be safely exposed to a greater degree of cold than in a damp climate, like the winter of the seaboard States.

Precipitation.—An important factor in the case is the amount of precipitation (rain or snow) to be expected during the feeding period. In cold weather the low temperature of the water which penetrates to the skin of animals is the cause of a loss of heat which may be regarded as practically an addition to that due to the cold air, the extent of both losses being affected by the thickness of the animal's coat. Far more important than this, however, is the expenditure of heat required to dry out the coat after it is wet, and this, as it would seem and as some of the experiments with sheep seem to indicate, would be greater with the heavier coated animal when it has once become thoroughly wet. Still greater, relatively, is the heat required to melt snow falling on the animal, or upon which it is compelled to lie.

These effects, it will be observed, are largely independent of the indications of the thermometer, and it is clear that the nature of the climate as regards humidity and precipitation is quite as important a factor as the temperature in its bearing on the question of shelter, and that in many localities a roof to shelter the animals from storms may be as efficient as a tight barn. One advantage of the roof, already mentioned incidentally, is that it provides the possibility of a dry bed, thus not only adding to the comfort of the stock but avoiding expenditure of energy in warming up or evaporating water or melting snow or ice.

Wind.—All are familiar with the greater severity of a windy day as compared with a still one of the same temperature. A large part of the protective value of the clothing of man or the coat of an animal resides in the air entangled between the fiber of the material. Wind tends to replace this air with fresh, cold air and thus greatly reduces the protective effect. A wind-break, therefore, may have a distinct economic value in stock feeding.

Temperature of drinking water.—In general, the same considerations adduced in discussing the influence of the temperature of the air apply to that of the drinking water. Under heavy feeding, especially, unless in very cold quarters, the animal has a surplus of heat which it can apply to warming its drink. If, then, the latter is at a temperature to be consumed freely there would seem to be no occasion for heating it further, except for one important consideration. The temperature of the air acts continuously and with approximate uniformity. That of the water, on the other hand, acts only at intervals, often only two or three times per day. If, now, the animal consumes within a short time a large amount of cold water, a correspondingly rapid expenditure of heat is required to warm this water to the body temperature, and this demand may for a time exceed the supply of surplus heat and cause an increased oxidation of tissue or food material for the sake of heat production only. Such a loss can never be made good at a later hour, since, once converted into heat, the energy has escaped from the grasp of the body. Other things being equal, then, it will clearly be desirable to have the water consumption approximate as nearly as possible a continuous consumption by having it constantly accessible, while if stock are watered only at intervals the temperature of the water may need to be rather higher than in the other case.

Insolation.—The effects of the weather are appreciably modified by the exposure of stock to direct sunlight. Aside from any direct effect of the light as such, a not inconsiderable amount of heat is imparted to the body by the sun's rays. During cold weather this is likely to be a distinct advantage, but during the hot months the reverse is true. Since the animal can not reduce its heat production below that required for its internal work and for the digestion and assimilation of its food, it may seriously tax its powers to dispose of the additional heat imparted by the direct sunlight. In this case shelter of some sort may be required for opposite reasons to those obtaining during the cold months. For similar reasons a supply of cool, fresh water, and exposure to the wind may be of great advantage in helping the animal to get rid of its surplus heat.

VENTILATION AND LIGHT.

Scarcely any data are available as to the influence of these two factors apart from their relations to heat production. There is no question, however, that proper ventilation and reasonably light quarters will tend to promote the welfare of the stock, both by rendering the conditions less favorable for the development and transmission of germ diseases and by a direct effect upon the health and resisting powers of the animals.

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Issued November 28, 1908.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 109.

A. D. MELVIN, CHIEF OF BUREAU.

PROTEOLYTIC CHANGES IN THE RIPENING OF CAMEMBERT CHEESE.

BY

ARTHUR W. DOX,
Chemist in Cheese Investigations, Dairy Division.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., September 21, 1908.

Sir: I have the honor to transmit herewith a manuscript entitled "Proteolytic Changes in the Ripening of Camembert Cheese," by Arthur W. Dox, chemist in cheese investigations, Dairy Division, and recommend that it be published as Bulletin 109 of this Bureau. This paper deals with work carried on at the Storrs (Conn.) Agricultural Experiment Station, by cooperation between that station and the Dairy Division of this Bureau.

Respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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PROTEOLYTIC CHANGES IN THE RIPENING OF CAMEMBERT CHEESE.

INTRODUCTORY.

Until comparatively recent years the changes that take place in the ripening or curing of the different varieties of cheese were but little understood. Although the practice of cheese making has been carried on for centuries, all of our knowledge of the chemical changes involved in the ripening process and the various factors that bring about these changes has come to us within the past fifty years. The earliest record we have of any discussion of this subject from a chemical point of view was published only a century ago. In this paper the French chemist, Chaptal,[1] [a] discusses the ripening of Roquefort cheese and advances certain theories to account for the changes in appearance and flavor which this cheese undergoes during its sojourn in the natural ripening caves. Biological factors were, of course, not taken into account in Chaptal's paper, for that phase of the subject was unknown until the time of Pasteur.

No scientific study of the subject, however, was made until the latter half of the nineteenth century. The attention of chemists was then directed to Roquefort cheese by a paper published by Blondeau[2] in 1864. Blondeau analyzed cheeses in different stages of ripening and found that the fat content increased from 1.85 per cent in the fresh cheese to 32.31 per cent in the cheese two months old. This enormous increase in the fat he ascribed to a synthesis of fat from protein by the mold. But a comparison of his figures for the other constituents of the cheese as well as the fat with analyses to be found in any modern book on dairy products will show their utter impossibility. This inaccurate work of Blondeau, however, served the purpose of directing the attention of other investigators to the subject, and during the next few years the changes in the fat content of cheese were studied by Brassier,[3] Sieber,[4] Jacobstahl,[5] and Von Nägeli and Loew.[6]

By this time the subject of cheese ripening had begun to arouse considerable interest among scientific investigators, and their researches were extended to other varieties of cheese. Swiss cheese and Cheddar cheese in particular received considerable attention. Among those who worked with Swiss cheese were Weidmann,[7] Röse,[8] Schulze,[8] and Winterstein.[9] In our own country the Cheddar type of cheese has been made the subject of thorough chemical investigation, and in this connection reference is made to the work of Babcock and Russell[10] and that of Van Slyke and Hart.[11] The German investigators made a special study of the products of proteolysis, while those in this country studied more particularly the factors that cause the ripening.

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[a] The figures refer to list of literature at end of bulletin.

All this work, however, deals with the "hard" cheeses. In this class of cheeses the ripening factors are the enzymes or unorganized ferments present in the fresh curd and the bacteria which occur in enormous numbers in the cheese. Such cheeses require several months for ripening, for the enzymes are present in very small amount, and the bacteria do not produce rapid proteolytic changes. In contrast to the hard cheeses we have another distinct class known as the soft cheeses. The cheeses belonging to this class differ mainly from those of the former class in that they contain a much higher percentage of water. This higher moisture content is much more favorable to the development of micro-organisms, and the ripening proceeds with greater rapidity.

PROCESSES IN THE RIPENING OF CAMEMBERT CHEESE.

The variety of soft cheese which we shall consider in this paper is the Camembert type, a soft cheese ripened mainly by a surface growth of mold. Of late years it has attained considerable importance in the cheese market, and the public is now more or less familiar with it. Although it is still imported from France in large quantities, its manufacture has been undertaken on a commercial scale in our own country with considerable success. The researches carried on by the Dairy Division of the Bureau of Animal Industry, in cooperation with the Storrs Agricultural Experiment Station, with a view to introducing the manufacture of Camembert cheese into the United States, have given very gratifying results.[12] For a description of the details of its manufacture the reader is referred to a bulletin by T. W. Issajeff.[14]

The biological factors essential to the production of Camembert cheese are the lactic-acid bacteria, which are normally present in milk, and two molds, *Penicillium camemberti* Thom[13] and *Oidium lactis.* Other molds that may be present are generally contaminations and often deleterious to the cheese. The penicillium is the mold that produces the actual ripening or digestion of the curd, while the oidium seems to be connected in some way with the flavor production. The oidium by itself or in conjunction with the lactic-acid bacteria can not ripen a cheese more than a few millimeters below the surface.

The ripening of all cheeses being essentially a hydrolysis of the paracasein or cheese curd through the agency of various enzymes, the end products or simple substances from which the complex protein molecule is built up are set free in varying amounts during the course of the ripening period. At the same time secondary reactions may occur which involve not only hydrolysis, but also oxidation, reduction, desamidation, and removal of carboxyl groups. The products of simple hydrolysis may thus undergo further changes with the formation of substances differing widely in chemical constitution from the substances from which they were derived. The successive steps of such reactions are often difficult to follow, and it is sometimes impossible to ascertain precisely what the mother substance is. In most cases, however, the secondary changes involve but one step, the removal of a certain radical from the original hydrolytic product. These changes are caused for the most part by bacteria, and in a cheese where the ripening is produced almost entirely by other agencies they are of minor importance. Where they do occur they result not from the direct action of an enzyme acting outside the cell wall of the organism, but rather from activities dependent upon the life history and metabolism of the organism. For this reason the center of a hard cheese shows the same flora and the same chemical composition as the portion near the rind. With cheeses of the Camembert-Brie type, however, there is a marked difference in this respect. The actual ripening here is caused by the proteolytic enzyme of the mold. This enzyme is secreted by the mold growing on the surface of the cheese and diffuses toward the center, digesting the curd through which it passes until the cheese is ripe. The fact that the ripening begins at the surface and proceeds toward the center indicates that the enzyme is produced in the mycelium of the mold. The progress of the ripening is very easy to follow, for the texture and color of the ripened portion are quite different from those of the unripened curd, and there is always a sharp line of demarcation between the two. The mycelium of the mold does not penetrate more than a few millimeters into the cheese, forming a sort of rind which is removed when the cheese is eaten.

The fresh Camembert cheese differs from the fresh curd of other whole-milk cheeses mainly in the greater amount of whey it contains. This slightly increases the relative amount of the other proteins, lactalbumin, whey protein, and lactoglobulin, as well as that of the nonnitrogenous constituents—lactose, citric acid, and inorganic salts. The amount of butterfat in the cheese varies merely with the richness of the milk. Paracasein, however, is the only protein present in any considerable amount, and the end products of the ripe cheese may be considered as derived from it. Moreover, the other three proteins mentioned above yield the same primary disintegration products, and a distinction as to the origin of the latter can not be made.

The proteolytic changes which constitute the ripening of Camembert cheese consist, therefore, in the changes which this paracasein undergoes through the action of proteolytic enzymes. As has already been mentioned, the principal factor is the enzyme secreted by the Camembert penicillium. Other enzymes are present, however, and a brief discussion of these will follow. No appreciable proteolysis occurs until after the cheese is nearly 2 weeks old. But in the meantime certain changes take place in the character and solubility of the curd. These changes have been studied by Bosworth.[15] They consist mainly in the liberation of paracasein from combination with calcium, due to the formation of lactic acid by lactic acid bacteria. At the same time the paracasein is converted into a form completely soluble in 5 per cent salt solution, and later it becomes insoluble again. As these are not, strictly speaking, proteolytic changes, a detailed discussion will not be given here.

ENZYMES IN THE CHEESE.

With the exception of the enzyme secreted by the mold and of a smaller variety of bacteria, Camembert contains the same ferments that are present in other cheeses. Like the hard cheeses, it contains the milk enzyme galactase, the rennet enzyme chymosin added in the curdling process, and lactic acid bacteria. In the case of the Cheddar type of cheese the action of these three factors has been studied in detail. Babcock and Russell found that galactase and rennet (pepsin) were important agents in the ripening of this variety of cheese. According to Van Slyke and Hart,[11] the rennet alone is capable of ripening a cheese. In their experiments the galactase was first destroyed by heat and then chloroform added to prevent the development of bacteria, yet the ripening went on, though not as rapidly as in the normal cheese, and the character of the chemical products was somewhat different. Thus there was a predominance of paranuclein, caseoses, and peptones, and an abnormally small amount of amino-acids. The entire absence of ammonia was very striking. The function of the bacteria in this variety of cheese has been studied by Rogers.[16] He came to the conclusion that the enzymes produced by the bacteria were responsible for most of the digestion beyond the peptone stage, and consequently the characteristic flavors.

In the short time required for the ripening of Camembert cheese the rennet, galactase, and lactic acid bacteria produce no appreciable digestion. This conclusion was reached by Bosworth, and the experience of the writer confirms it. Even the hard cheeses which are ripened entirely by these agents undergo very little change during the first month. A Camembert cheese, however, should be ripe at the end of a month, and at the same time should contain a greater amount of primary digestion products. This ripening must be due almost entirely to the mold enzyme, for the interior curd, which has not yet been reached by this enzyme, but contains all of the other ferments, shows little evidence of digestion. If the unripened curd in the center of a Camembert cheese three or four weeks old be subjected to chemical analysis it will be found that the paracasein is scarcely altered except for the fact that it is liberated from combination with calcium. The galactase can not play more than a very subordinate rôle, as is shown by the fact that the cheese ripens normally when made from milk which has been pasteurized at a temperature sufficiently high to impair greatly, if not destroy, the activity of this enzyme. Likewise the rennet can not be of more than minor importance as a ripening factor. Recent investigations have shown that chymosin or rennet enzyme is identical with pepsin. But, as will be seen later, the ripening of Camembert cheese bears no resemblance to a peptic digestion. The rennet should show its greatest activity in the interior curd, which is quite strongly acid. But owing to the short duration of the ripening period and the small amount of rennet present, the proteolytic action of the latter is practically negligible. Aside from the hydrolysis of the casein into paracasein and whey protein, its action is inappreciable. The unripened curd shows no evidence of peptic digestion.

The lactic acid bacteria which constitute nine-tenths of the bacterial flora of the cheese serve the purpose of converting the milk sugar into lactic acid, thus producing conditions unfavorable to the development of other bacteria. They are probably responsible for the peculiar flavor which is characteristic of the acid curd in the interior of a Camembert cheese. Their proteolytic action is otherwise hardly noticeable. Experiments in which sterile curd was inoculated with these organisms show that the amount of diffusible nitrogen increases only very slightly at the end of a month, even in the presence of calcium carbonate, which neutralizes the acid.

We are safe in assuming, therefore, that these three proteolytic factors—the galactase, the rennet, and the lactic acid bacteria—have very little to do with the actual ripening of the cheese, this being essentially the work of the enzyme from the mold.

As has already been pointed out, the mold of Camembert cheese (*Penicillium camemberti*) secretes a powerful proteolytic enzyme, which is undoubtedly the most potent factor in the ripening of this cheese. The fact that the ripening begins at the surface and proceeds toward the center indicates that the enzyme is produced in the mycelium of the mold and diffuses inward. The diffusibility of this enzyme is also shown by the fact that synthetic culture media upon which this mold has grown for some time have a marked proteolytic activity. Experiments are now being instituted to determine the exact nature of this enzyme and the extent to which it will hydrolyze certain proteins. The results thus far obtained seem to indicate that it is of the nature of erepsin. It attacks casein and peptone readily, but is without action upon fibrin and coagulated egg albumin.

Vines[17] has shown that erepsin is very widely distributed in the vegetable kingdom. This vegetable "ereptase," as he calls it, differs from animal erepsin in that it is most active in the presence of the natural acid of the plant. The addition of other acids, or of an alkali, greatly impairs its activity. As long as the acidity is due entirely to acid phosphates, the activity of this ereptase is very pronounced, but the presence of free acid in the medium is inhibitory. It is readily seen, therefore, that a fresh Camembert cheese offers very favorable conditions for the action of ereptase. In the first place, casein and paracasein are readily attacked by this enzyme. In the second place, the lactic acid produced by the bacteria does not accumulate but combines with the calcium phosphate, forming calcium lactate and mono-calcium phosphate. The acidity of the cheese is due to the presence of the latter salt.

In this connection, however, it must be remembered that the same results are not necessarily obtained with enzymes in the presence of an antiseptic as with organisms *in vivo*. In the case of Camembert cheese where the proteolysis is effected by diffusion of the enzyme rather than by diffusion of the substratum, the conditions more nearly approach those met with in an artificial digestion experiment. Nevertheless there are certain striking differences which will be pointed out later. A discussion of the enzymes obtained from a pure culture of this organism will be reserved for a future paper.

PROTEOLYSIS OF CASEIN.

When casein or any other protein is boiled with strong acid or alkali, a decomposition takes place with the production of simpler substances. These simple substances resulting from such decomposition have of late years been studied by a number of investigators. A similar decomposition occurs when the protein is acted upon by proteolytic enzymes. These enzymes also have the power of transforming casein into bodies of less molecular complexity. The changes are of a hydrolytic nature, the original molecule being broken successively at different places and a molecule of water entering at the point of cleavage. The extent to which the protein is hydrolyzed, and consequently the nature of the resulting products, depends upon the enzyme. Pepsin, obtained from the gastric juice, does not carry the proteolysis beyond the peptone stage, while trypsin, obtained from the pancreas, breaks up the protein into crystalline end products. Erepsin, on the other hand, does not attack native proteins, with the exception of casein, but acts readily upon proteoses and peptones. The enzyme isolated by the writer from Camembert mold resembles erepsin in this respect.

NITROGENOUS CONSTITUENTS OF THE CHEESE.

The ripening of Camembert cheese being a proteolysis, certain digestion products may be expected to occur in the ripened cheese. As casein, or rather paracasein, forms the main bulk of the proteins in the curd, it would therefore undergo the same changes that occur when casein is digested artificially with an enzyme, though the proteolysis is never allowed to go on as far in a cheese as is usually done in an artificial digestion experiment. The products may be grouped roughly into the following classes: Caseoses, peptones, polypeptids, amino-acids, and ammonia. Methods for the separation of these groups of substances from cheese have already been elaborated by Van Slyke and Hart.[11] They consist in extracting the cheese with water, and determining the nitrogen in the precipitates obtained by the addition of various reagents to aliquot portions of this extract.

In the subsequent pages of this article the separation of the individual members of these groups will be discussed. The cheeses used for this work were made at the Storrs Experiment Station, and were pronounced by experts to be equal in texture and appearance to the imported brands. Both texture and flavor showed them to be excellent cheeses of the Camembert type.

The analysis of a ripe cheese by the method of Van Slyke and Hart showed the nitrogenous constituents to be present in the following amounts:

Nitrogen as—	Per cent of cheese.
Total nitrogen	2.47
Water—soluble	1.79
Precipitated by hydrochloric acid	.40
Caseoses	.10
Peptones	.28
Amino-acids	.82
Salt—soluble (paracasein)	.15
Ammonia	.19

The polypeptids are included under the peptones and amino-acids. This represents the analysis of an individual cheese. Some variations occur with different samples, but the differences are only slight with cheeses at the same stage of ripening. As none of the individual members of these groups of digestion products had ever been isolated from Camembert cheese, a determination of some of the more characteristic ones was considered advisable. Proximate analyses of the cheese at different stages of ripening will be found in Bosworth's paper.[15] These analyses show merely the rate of formation or destruction of three broad groups of digestion products, and throw little light upon the nature of the ripening from the biochemical standpoint. The writer has attempted to determine, as far as the facilities at his command permitted, the relative amounts of the more important members occurring in these groups. They will be discussed in the same order as the groups are determined in Van Slyke and Hart's method for the analysis of cheese.

HYDROCHLORIC ACID PRECIPITATE.

When an aqueous extract of the cheese is made and acidified with hydrochloric acid, a white curdy precipitate appears, which on warming to 50° C. clots together into a gummy mass. If the digestion were of a peptic nature this precipitate should consist of paranuclein. The chief characteristics of this altered phosphoprotein are its high phosphorus content and the comparative slowness with which it is further acted upon by pepsin. On the other hand, trypsin converts casein directly into caseoses without the formation of paranuclein, and at the same time liberates the phosphorus in the form of phosphoric acid. Erepsin probably acts in the same way as trypsin in this respect. Again, the precipitate might be a coagulose or protein synthesized by the reversed action of a proteolytic enzyme. Such a coagulose is Kurajeff's plastein, formed by the action of rennet on albuminoses.

A similar precipitate has been obtained from other varieties of cheese and has usually been regarded as paranuclein. As the ripening of Camembert cheese is not a peptic digestion, it seemed unlikely that this precipitate could be paranuclein. In order to determine more precisely the nature of the precipitate, several cheeses were subjected to the following treatment.

An aqueous extract was made by stirring the macerated cheese with water in a bath maintained at a temperature of 50° C. This extraction was repeated several times, filtering off the liquid at the end of half an hour through cotton and asbestos, and adding fresh quantities of water until the filtrate was practically free from nitrogenous matter. The extract made in this way was acidified to 0.2 per cent with hydrochloric acid, whereupon a white curdy precipitate resulted. The precipitate was washed thoroughly with acidulated, then with distilled, water, and finally dried in a desiccator and extracted with ether to remove adhering fat.

Upon testing the solubilities of this precipitate, it was found that a small part of it dissolved in 5 per cent sodium chlorid solution, while the greater part was soluble in 50 per cent alcohol. The smaller fraction was studied first. It dissolved in alkalies, was reprecipitated by acids, excess of which dissolved the precipitate.

The substance was readily attacked by trypsin, dissolving completely in twenty-four hours, and giving a solution from which no precipitate was obtained by saturation with ammonium sulphate. A sample dried at 110° C. gave the following analysis, based upon the ash-free substance. Alongside it are given Röse's analysis of paracasein and Chittenden's[18] analysis of paranuclein, with the phosphorus as found by Jackson.

	Substance from cheese.	Paracasein (Röse).	Paranuclein (Chittenden).
Carbon	53.63	53.94	51.29
Hydrogen	7.08	7.14	7.26
Nitrogen	15.10	15.14	15.23
Sulphur	.98	1.01	.68
Phosphorus	.50	....	2.75
Ash	.82	....	12.43

A comparison of these analyses shows that the substance is too low in phosphorus to be paranuclein. The analysis agrees fairly well with that of paracasein, and it can be regarded as paracasein from which a part of the phosphorus has been liberated by enzyme action. Paracasein probably contains about the same amount of phosphorus as casein itself, which, according to Hammarstein, is 0.85 per cent.

The alcohol-soluble part of the precipitate was dissolved in 50 per cent alcohol, filtered and poured into water. A gummy precipitate was formed. It was dried at 110° C., extracted with ether, and analyzed. On fusing the substance with potash and niter for the sulphur determination, a strong odor of skatol was emitted, stronger than that obtained with casein. This indicates the presence of the tryptophane group. The ready solubility in alcohol and insolubility in water are properties characteristic of caseoglutin, a substance discovered in Swiss cheese by Weidmann. The analysis, together with Röse's analysis of caseoglutin, follows:

	Substance from cheese.	Caseoglutin (Röse).
Carbon	54.34	54.4
Hydrogen	7.30	7.34
Nitrogen	15.37	15.29
Sulphur	.95	.95
Phosphorus	.06	....
Ash	.28	....

Both the analysis and the properties of this substance agree with those of caseoglutin.

COAGULABLE PROTEINS.

Winterstein found in Swiss cheese a small amount of a substance which was precipitated from acid solution by boiling. This substance he calls tyroalbumin. Its exact nature has not yet been determined.

Several attempts were made to find this substance in Camembert cheese, but so far they have resulted in failure. On heating the filtrate from the caseoglutin to boiling, both in acid and in neutral solution, no precipitate was obtained.

CASEOSES.

These, together with the peptones, are the intermediate disintegration of casein by ordinary proteolytic enzymes. They can not be regarded as homogeneous substances, as they represent transition products formed by the loss of varying numbers of amino-acid molecules from the original protein. They can, however, be separated into groups according to their solubilities. A method for the separation of albumoses by fractional precipitation with ammonium sulphate was elaborated by Pick.[19] If nitrogen determinations are to be made, the ammonium sulphate must be removed by dialysis, a long and tedious operation. To obviate this difficulty Zunz[20] used zinc sulphate and found that the precipitation limits were quite as sharply defined. As the elementary analyses of these groups of caseoses have very little value, and the peptones were to be separated from the filtrate, the method of Pick was used in this work. These saturation limits can not, however, be regarded as reliable indexes of individuality.

The caseoses of the cheese were separated into the four fractions described by Pick. They are designated as follows: Protocaseose, by half saturation of the neutral solution with ammonium sulphate; deuterocaseose A, by two-thirds saturation; deuterocaseose B, by complete saturation; and deuterocaseose C, by acidifying the filtrate from B. In the early stages of ripening, the protocaseose predominates. In the ripened cheese, however, protocaseose and deutero B are present in about equal amounts, and together form about three-fourths of all the caseoses. A distinction will be noticed here from the albumose formation observed by Zunz in peptic digestion. According to Zunz, after deutero B has reached its maximum, deutero A predominates, and finally deutero C.

In purifying the different fractions, the method of Haslam[21] was followed out, viz, rubbing the precipitate in a mortar with ammonium sulphate solution of the same concentration as the filtrate. Several reprecipitations were made before the product was finally freed from ammonium sulphate by repeated precipitation with alcohol.

The first fraction should contain, besides protocaseose, heteroalbumose if this substance were present in the cheese. Heteroalbumose could not be derived from casein. Traces were found, however, but they probably came from albumin. Upon subjecting the carefully purified protocaseose to dialysis, a slight residue was left which would not diffuse. The amount was too small for chemical examination, but it was probably heteroalbumose. All the fractions gave the biuret reaction, and all except deutero C gave the Millon reaction. The intensity of the lead sulphid reaction seemed to diminish progressively, until with deutero C it was just perceptible.

PEPTONES.

The filtrate from the caseoses was nearly neutralized with ammonia and treated with a saturated solution of ferric ammonium sulphate. A gelatinous brown precipitate resulted. This corresponds to the alpha and beta peptones of Siegfried.[32] The precipitate was filtered off, washed with a saturated solution of iron alum, and decomposed by barium hydrate. After filtering off the ferric hydroxid and barium sulphate, a current of air was drawn through the alkaline solution until the ammonia was expelled. The barium was then removed by sulphuric acid, and the solution concentrated under diminished pressure and poured into a large volume of alcohol. A precipitate was obtained which is analogous to Winterstein's alpha peptone. The filtrate still contained peptone, as was shown by an intense biuret reaction. Further addition of alcohol gave no precipitate. The solution must therefore contain an alcohol-soluble peptone—Winterstein's beta peptone. It was reprecipitated, after distilling off the alcohol, by phosphotungstic acid, the precipitate decomposed by barium hydroxid, and the barium removed by sulphuric acid, carefully avoiding an excess. The solution was then evaporated to dryness. The resulting beta peptone may have contained slight admixtures of polypeptids, but further purification was not attempted.

The alpha peptone gave no Millon reaction and a strong furfurol reaction. Beta peptone, on the other hand, gave a strong Millon reaction, but no furfurol reaction. Both gave the characteristic red biuret reaction, xanthoproteic reaction, and a slight lead sulphid reaction. Dried at 105° C., alpha gave 15.10 and beta 14.80 per cent nitrogen. In this case the analytical figures have very little value, as the substances are hygroscopic, and on drying continue to lose water until a temperature is reached which causes a slight decomposition. The two peptones were present in about equal amount and together comprised about 1.6 per cent of the cheese. They had the bitter taste characteristic of peptones.

POLYPEPTIDS.

After removal of the caseoses and peptones by means of lead acetate, carefully avoiding an excess of the reagent, the cheese extract still gave a biuret reaction. The polypeptids are the intermediate products between peptones and amino-acids. Some of them give a biuret reaction, and their presence is probably the explanation of this phenomenon. Some are precipitated by lead acetate, while others remain in solution. Fischer and Abderhalden obtained by the tryptic digestion of casein a polypeptid, which on hydrolysis yielded alpha-pyrrolidin-carboxylic acid and phenylalanin. These two acids were not found in the free state, and their absence has been regarded as characteristic of tryptic digestion. Whether or not erepsin decomposes this polypeptid is not yet known. It is very probable that other polypeptids exist, temporarily at least, as transition products from the peptones to the amino-acids. Many of them would be destroyed by the action of the mold, while others would be more resistant. Abderhalden[23] found that *Aspergillus niger* grows readily on glycylglycin and dileucylglycylglycin, two polypeptids that are not attacked by trypsin. Winterstein regards his alpha peptone as similar in many respects to Fischer's polypeptid. This, however, would seem improbable, in view of the fact that he has demonstrated phenylalanin and prolin in the cheese. No satisfactory method has yet been found for separating the polypeptids as a group, and the amount present in a cheese can only be a matter of conjecture. The polypeptids will be made the subject of future study in this connection.

DIAMINO-ACIDS.

The next group of substances to be studied was the diamino-acids, or hexone bases. The three hexone bases, along with ammonia, can be determined quantitatively, and for that reason they have received more attention from investigators studying the disintegration products of the proteins than have the monoamino-acids. They can be expressed in definite figures, whereas the other disintegration products have to be expressed in minimal values. They have already been found in cheese—in Swiss cheese by Winterstein and Thöny, and in Cheddar cheese by Van Slyke and Hart. Owing to the softer consistency of Camembert cheese a somewhat different method of procedure was adopted in making the extraction.

Three kilograms of the thoroughly ripened cheese made at the Storrs Experiment Station were ground in a mortar and extracted six times with warm water, according to the usual method of analysis, until the volume of the liquid was about six liters. The greater part of the fat rose to the surface and could easily be skimmed off. It was washed by stirring thoroughly with cold water and the filtrate mixed with the cheese extract. The remainder of the fat was found to be precipitated almost quantitatively with the proteins, and thus the necessity of extracting the original cheese with ether was obviated. The extract was filtered through cotton and through asbestos, then acidified with sulphuric acid and warmed until the caseoglutin had settled out, whereupon the liquid was filtered again. The solution was now concentrated at a low temperature until the volume was about two liters. About three volumes of alcohol were added to precipitate the greater part of the caseoses and peptones. After filtering off this precipitate the alcohol was distilled off under diminished pressure, and tannic acid added to precipitate the rest of the caseoses and peptones. The excess of tannic acid was removed by lead acetate and the lead by sulphuric acid. The resulting solution still gave a biuret reaction. It contained, besides traces of secondary disintegration products and polypeptids, the hexone bases, amino-acids, and ammonium salts, together with the sodium chlorid present in the cheese.

The hexone bases were precipitated by a 50 per cent solution of phosphotungstic acid in the presence of 5 per cent sulphuric acid. A large amount of this reagent had to be added before the precipitation was complete, and a voluminous white precipitate was obtained. After standing several days it was filtered off and washed with 5 per cent sulphuric acid containing a little phosphotungstic acid. The washing was a long and tedious operation. It was found necessary to remove the precipitate each time from the funnel and grind it with the sulphuric acid in a mortar. This was repeated until all of the sodium salts had been removed.

For the separation of the bases Kossel's[24] older method was used, after removal of the phosphotungstic and sulphuric acids by barium hydroxid and passing in a current of air to expel the ammonia. The excess of barium was removed by carbon dioxid, and mercuric chlorid added to precipitate the histidin. This precipitate was allowed to stand several days, then filtered and washed again. It was suspended in water and decomposed by hydrogen sulphid after slightly acidifying with sulphuric acid. The filtrate from the mercuric sulphid was boiled with charcoal until practically colorless, and precipitated with silver nitrate and ammonia. The arginin was precipitated by saturating the solution with barium hydroxid, and adding silver nitrate until a drop of the solution gave a brown color on the addition of silver nitrate. The arginin silver was decomposed by hydrochloric acid and hydrogen sulphid, filtered, boiled with charcoal, and evaporated to crystallization. The filtrate from the arginin was freed from barium and silver by means of sulphuric acid and hydrogen sulphid, and an alcoholic solution of picric acid added. The lysin picrate did not crystallize readily, but after several crystallizations the characteristic yellow needles were obtained. The bases were found in the following amounts: Histidin, 1.1 grams; arginin, 0.6 gram; and lysin, 1.9 grams. Histidin was analyzed in the form of the silver salt, arginin as the chlorid, and lysin as the picrate. The free histidin gave an intense red color with diazobenzenesulphanilic acid. The analyses of the bases are given below:

Histidin silver, $C_6H_7N_3O_2Ag_2H_2O$.

(Beta-imidoazol-alpha-aminopropionic acid.)

	Calculated.	Found.
Argentum	55.81	55.60
Nitrogen	10.85	10.78

Arginin hydrochlorid, $C_6H_{14}N_4O_2HCl$.

(Delta-guanidine-alpha-aminovalerianic acid.)

	Calculated.	Found.
Chlorin	16.87	16.70
Nitrogen	22.60	22.50

Lysin picrate, $C_6H_{14}N_2O_2C_6H_3N_3O_7$.

(Diaminocaproic acid.)

	Calculated.	Found.
Nitrogen	18.66	18.50
Carbon	38.40	38.53
Hydrogen	4.53	4.54

The other bases were present in so small amount (about 0.5 gram) that no attempt was made to isolate them. A noteworthy fact is that arginin, which was not found at all in Swiss cheese, is present here. It is possible that some of it is further hydrolyzed into guanidin and aminovalerianic acid or into urea and ornithin (diaminovalerianic acid). The filtrate from the histidin, arginin, and lysin had a very faint but characteristic odor of tetramethylenediamin. This substance would result from the liberation of carbon dioxid from ornithin, one of the cleavage products of arginin. It could not have been present, however, in more than traces. An attempt was made to separate guanidin in the form of the gold salt, but no crystals could be obtained. The small amount of bases remaining in the lysin fraction indicates that the occurrence of secondary reactions in this group is very slight.

MONOAMINO-ACIDS.

A complete separation of all the amino-acids remaining in solution after removal of the intermediate disintegration products and hexone bases can be accomplished only by Fischer's method of distilling the ethyl esters in vacuo. This necessitates delicate and costly apparatus which the writer did not have at his command. Certain of the amino-acids, however, can be separated almost quantitatively from the mixture without resorting to the method of esterification. Among these are glutaminic acid, tyrosin, and leucin.

Another lot of cheese (3 kilograms) was treated in the manner described above to remove the caseoglutin, caseoses, and peptones. The residue was evaporated to a small bulk, saturated with hydrochloric-acid gas, and kept at zero for several days. Crystals were deposited on the walls of the flask, and a pulverulent precipitate separated out on the bottom. These were found to consist of glutaminic acid, hydrochlorid, and sodium chlorid. They were transferred to a Büchner funnel and washed with concentrated hydrochloric acid, then dissolved in water. The solution was neutralized with caustic soda and boiled with freshly precipitated copper hydroxid. A blue precipitate was formed. It was filtered and washed, and then suspended in water slightly acidified, and decomposed by hydrogen sulphid. The free acid thus obtained was again saturated with hydrochloric-acid gas and allowed to crystallize as before. The colorless crystals thus obtained were decomposed by the calculated amount of caustic soda (30 c. c. N–NaOH), and the free acid crystallized out. About 5 grams of crystals were obtained. Analysis gave the following figures:

Glutaminic acid, $C_5H_9NO_4$.

(Aminoglutaric acid.)

	Calculated.	Found.
Carbon	40.82	40.62
Hydrogen	6.13	6.15
Nitrogen	9.52	9.53

The filtrate from the glutaminic acid was treated with lead carbonate to remove the bulk of the hydrochloric acid, and the lead remaining in solution was removed by sulphuric acid. After filtering and neutralizing, the solution was evaporated to incipient crystallization. The first crop of crystals should contain tyrosin and traces of leucin, and the second leucin with traces of tyrosin. The two constituents of each fraction were separated by treatment with glacial acetic acid. The leucin purified in this way gave no color with Millon's reagent. The tyrosin was tested for sulphur by fusing a portion of it with sodium carbonate and adding sodium nitroprussid to the aqueous solution. No coloration was obtained, indicating the absence of cystin. About 8 grams of tyrosin and 14 grams of leucin were obtained. It must be borne in mind that while the greater part of the glutaminic acid and leucin can be isolated in this way, the amounts do not represent strictly quantitative results, for a further yield is invariably obtained from the higher boiling fractions of the ethyl esters. Following are the analyses of the tyrosin and leucin:

Tyrosin, $C_9H_{11}NO_3$.

(P-hydroxyphenyl-alpha-aminopropionic acid.)

	Calculated.	Found.
Carbon	59.66	59.53
Hydrogen	6.07	6.00
Nitrogen	7.73	7.69

Leucin, $C_6H_{13}NO_2$.

(Alpha-aminoisobutylacetic acid.)

	Calculated.	Found.	
		First crop.	Second crop.
Carbon	53.96	54.99	54.82
Hydrogen	9.92	9.89	9.62
Nitrogen	10.68	10.53	10.76

The tyrosin gave the characteristic color reactions, viz, a red color and precipitate with Millon's reagent, a bright red coloration with diazobenzenesulphanilic acid, and a yellow precipitate of nitrotyrosin nitrate with nitric acid. Under the microscope it showed the characteristic wavy needles.

The leucin was also characteristic under the microscope. Heated on a platinum foil it sublimed completely, emitting an odor like that of some of the higher alkylamins.

On further concentrating the filtrate from the leucin, a few needle-shaped crystals were obtained having a sour taste. They did not melt at 225° C. Not enough of the substance was obtained for analysis, but it was probably aspartic acid.

As has already been mentioned, the remainder of the amino-acids can not be separated without resorting to Fischer's method of distillation. Phenylalanin and tryptophan, however, can be detected qualitatively. On evaporating the solution to dryness and treating the residue with sulphuric acid and potassium dichromate, the writer felt confident that he detected the odor of phenylacetaldehyde, notwithstanding the presence of other aldehydes formed by the oxidation with dichromate. This would indicate the presence of phenylalanin, but from this test alone it would be impossible to say with certainty whether phenylalanin was really present or not.

A striking fact is that none of the cheeses examined responded to the tryptophan reaction with acetic acid and bromin water. Aqueous extracts of cheeses in all stages of ripening were examined, but in all cases they failed to give any coloration with this reagent. When the mold was grown upon milk the tryptophan reaction was likewise negative, although the casein was broken down into amino-acids, among which leucin and tyrosin were identified. On the other hand, the enzyme preparation from the same mold readily digests milk in the presence of toluol, and the tryptophan reaction is invariably positive. If tryptophan were liberated in the cheese, it might undergo further decomposition as a result of bacterial action. In this case the end products would be indol and skatol—characteristic products of putrefaction. Both of these substances would have given a coloration with the tryptophan reagent, and must therefore have been absent.

AMMONIA.

A normal cheese contains from 0.20 to 0.25 per cent of ammonia. The greater part of this is in combination with acid radicals, for while the ripened cheese is alkaline to litmus it is still acid to phenolphthalein. Some of the more highly flavored specimens, however, have a distinct odor of ammonia near the rind. The formation of ammonia does not begin until after the second week, then the amount steadily increases until the cheese is ripe. As long as the ripened portion does not extend more than a few millimeters below the mycelium of the mold no ammonia, either free or in combination, can be detected. Cheeses with a very strong flavor contain, as a rule, more ammonia than the milder ones. In cheeses that are overripe the presence of free ammonia can usually be detected by its odor. For the determination of ammonia, the writer has found Folin's method more satisfactory than the regular method of distilling the tannin filtrate with magnesium oxid. It can be used in the presence of proteins without effecting any decomposition.

ABSENCE OF PUTREFACTIVE PRODUCTS.

While the ripened cheese possesses a peculiar odor, which to some people is quite disagreeable, it does not resemble that of the typical putrefactive products, nearly all of which are characterized by a foul odor. Among the substances belonging to this class are indol, skatol, mercaptan, hydrogen sulphid, and phenols. Qualitative tests were made repeatedly for all of these substances on different samples of cheese, but in all cases they were negative, except in those cheeses that had gone past the usual ripening. After the ripening is complete putrefaction may set in if the cheese does not receive proper care. In those cases where some of the putrefactive products were found the cheeses were otherwise unfit for eating, as was evidenced by a very disagreeable odor and taste. Nearly all of these substances are found in Limburg cheese, but they do not occur in good Camembert cheese. The failure to find typical putrefactive products, together with the fact that the lysin fraction of the diamino-acids contained only traces of diamins, indicates that whatever the action of the bacteria in the cheese may be, they do not cause secondary reactions of this nature to any extent.

SUMMARY.

The following substances have been isolated from Camembert cheese: Caseoglutin, protocaseose, deuterocaseoses A, B, and C, alpha and beta peptones, histidin, arginin, lysin, glutaminic acid, tyrosin, and leucin.

Among those substances which the writer failed to find are paranuclein, tryptophan, indol, skatol, mercaptan, hydrogen sulphid, and phenols.

The ripening of Camembert cheese can not be a peptic digestion, as is shown by the following facts:

1. Paranuclein, the characteristic product of peptic digestion of casein, is absent.
2. The greater part of the phosphorus is liberated and appears as acid calcium phosphate. According to Plimmer and Bayliss,[25] pepsin acts slowly and incompletely, only 70 per cent of the phosphorus being liberated from casein in 149 days, and that mostly in the organic form.
3. Amino-acids and ammonia are present in considerable amount.

The ripening resembles ereptic digestion in many respects, as follows:

1. The reaction of the cheese before ripening, i. e., acidity caused by acid phosphates, is most favorable to the activity of ereptase.
2. The digestion proceeds beyond the peptone stage, with the formation of amino-acids and ammonia.
3. A separate study of the enzyme from the Camembert mold shows that this enzyme is a vegetable ereptase.

The absence of tryptophan, which is ordinarily liberated in ereptic digestion, is striking.

The presence of caseoglutin, the remarkable albumose-like body, is also noteworthy. This substance has not, to the writer's knowledge, been observed in digestions with pure enzymes.

ACKNOWLEDGMENTS.

In conclusion, the writer acknowledges his indebtedness to Prof. L. B. Mendel, of Yale University, and to Dr. B. B. Turner, formerly of the Storrs Experiment Station, for many helpful suggestions in carrying out this work.

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U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ANIMAL INDUSTRY.—BULLETIN 110, PART I.
A. D. MELVIN, CHIEF OF BUREAU.

A BIOMETRICAL STUDY OF EGG PRODUCTION IN THE DOMESTIC FOWL.

I. VARIATION IN ANNUAL EGG PRODUCTION.

BY

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1909.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., September 29, 1908.

Sir: I have the honor to transmit herewith and to recommend for publication in the bulletin series of this Bureau a manuscript entitled "A Biometrical Study of Egg Production in the Domestic Fowl. I. Variation in Annual Egg Production."

This paper is the first in a proposed series dealing with a biometrical study by Drs. Raymond Pearl and Frank M. Surface of the results obtained at the Maine Agricultural Experiment Station in breeding for egg production during the past nine years, the work during the past three years having been done in cooperation with this Bureau. The subjects to be discussed in the several parts are briefly outlined in the introduction.

While the investigation is the joint work of Doctors Pearl and Surface, Doctor Pearl is responsible for the actual writing of the whole paper.

Very respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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A BIOMETRICAL STUDY OF EGG PRODUCTION IN THE DOMESTIC FOWL.

I. VARIATION IN ANNUAL EGG PRODUCTION.[a]

INTRODUCTION.

In 1898 the Maine Agricultural Experiment Station began the use of trap nests[b] in connection with its poultry investigations. Since that time such nests have been used to obtain records of the egg production of all hens kept by the station. In consequence there has now accumulated a remarkable—in some respects, indeed, a unique—collection of exact statistical data regarding the phenomenon of egg production in certain breeds of the domestic fowl. So far as we are aware no other set of records of egg production exists which compares with this either in regard to the number of birds included in the statistics or in length of time covered by continuous daily records. On this account it has seemed desirable that these statistics be submitted to such thorough biometrical analysis as their intrinsic value obviously warrants. Hitherto practically no analytical study of egg production statistics (either the present collection or others) has ever been made. The need of such study, however, is apparent if it be considered that only by analysis of comprehensive statistics of egg production can we hope to reach a definite formulation of the fundamental biological laws underlying the process itself. The existing knowledge of egg production in fowls is on much the same plane as that regarding milk production in dairy cattle, for example. In both cases empirical methods have led to a knowledge of how to feed, care for, and, to some extent, breed the animals in order to get a high production of the thing desired. But of the biological factors concerned in improved egg production or milk secretion, and the laws according to which these factors operate, relatively little is definitely known.

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[a] Papers from the Biological Laboratory of the Maine Agricultural Experiment Station, No. 2.

[b] The particular type of trap nest used was designed at this station and has been described and figured in the Annual Report of the Maine Agricultural Experiment Station for 1898, pp. 141–143, in various bulletins of the station issued subsequently, and in Bulletin 90 of the Bureau of Animal Industry. Recently a new and improved trap nest has been devised and has replaced the earlier form of nest in the experimental work of the station. For a description of this new nest see Bulletin 159 of the Maine station.

In the case of the fowl the frequency of ovulation in a given period of time has been enormously increased in the domesticated hen as compared with the wild *Gallus bankiva.* It is commonly said that the great egg production of present-day "improved" varieties is due to the long-continued process of selection for this quality or characteristic which has been going on since domestication of fowls began. Possibly this is true in a broad sense, but it does not tell us anything about the underlying physiological factors which are the things that have been improved by this selection, or even what these factors are. Yet it is about them that we must know if we are to make advance in the direction of increasing egg production. Selection must be directed with ever-increasing precision as it goes on if improvement is to continue, and to make it more precise the breeder must have more detailed knowledge regarding the thing for which he is selecting, and how this is inherited.

A point of particular biological interest in connection with statistics of egg production lies in the relation which they bear to statistics of fecundity and fertility in other organisms. In nearly all animals other than birds the only possible measure of fecundity is based on the number of young produced. But the number of young produced depends not alone on the mother's inherent reproductive capacity, but also on her opportunities for getting the ova she produces fertilized. Statistics such as those with which we are here dealing are statistics of *ovulation,* and they make it possible to study this single phase of the problem of fecundity free from disturbing factors.[a]

The general purpose of this study is to make as thorough an analysis of the phenomenon of egg production in the domestic fowl as may be possible. The detailed statistics which we have available are so extensive and the specific problems to be attacked are so numerous that it has seemed advisable to publish the results of the investigation in separate parts. The general topics which it is tentatively proposed shall be discussed in the several parts are briefly indicated in the following outline:

I. Variation in egg production based on the study of the records of annual production. (The present paper.)

II. The egg production in the several months of the year and the relation of monthly to total annual egg production. This portion of the investigation has as its aim the "dissection" of the gross annual curves of variation in egg production.

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[a] For a more detailed discussion of this point see Maine Agricultural Station Bulletin 166.

III. The effect of environmental influences on egg production.

IV. The relation of certain internal factors to egg production.

V. General summary and discussion of the results of the investigation.

The present paper (Part I) is in the first instance a necessary preliminary to those which are to follow. Its main purpose is, in a sense, to define the problems with which the subsequent parts of the work have to do. In it are set forth the facts regarding variation in first-year egg production.[a] These facts we shall attempt to analyze in later portions of the work. The subject of variation in first-year egg production has, however, a number of features of interest on its own account, and presents certain problems which can be answered without treating the more detailed statistics. First in importance is to learn definitely what the characteristics of variation in egg production in the individual are. To what kind of variation curves do statistics of ovulation lead? What are the biometrical constants of such curves? How does variation in annual egg production resemble or differ from variation in other characters, and in particular variation in fertility and fecundity? How are the variation constants for first-year production affected by environmental influences? In what way and to what extent has annual egg production been influenced by selective breeding? What relation exists between first-year and second-year production? These are some of the specific problems which will be considered in the paper.

MATERIAL.

Before undertaking a detailed account of the group statistics it will be well to make some statement regarding the homogeneity—from the biological standpoint—of the material from which these records have been obtained. As has been stated in publications of the Maine Agricultural Experiment Station, there has been conducted at this station during the last nine years an investigation under the direction of the late Prof. Gilbert M. Gowell on the subject of breeding hens for increased egg production. The statistical material with which the present paper has to do comprises the egg records obtained in the course of this breeding investigation. It will not be necessary to state here in detail the plan of this breeding work, since that has already been thoroughly done in Bulletin 90 of the Bureau of Animal Industry. In that bulletin (pp. 7–15) is given a detailed account of the methods used in this breeding work up to the year 1906. A general statement regarding this work will suffice for our present purpose.

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[a] The term "first-year egg production" will be used throughout as a convenient verbal contraction in the place of "the number of eggs produced by pullets in the year beginning the first day of the November following their hatching and ending a year from that date."

At the beginning of the experiment in 1898 three breeds of hens were used: (1) A strain of Barred Plymouth Rocks which had been bred by Professor Gowell for a period of some twenty-five years; (2) a strain of White Wyandottes which had been bred at the station for some years; and (3) a strain of Light Brahmas which similarly had been bred for some time at the station.

All the birds in hand at the beginning of the breeding experiment in 1898 were purebred in the ordinary sense and had for some years been bred by the same person—Professor Gowell. This insures that in regard to racial purity they form material which is, from a biological standpoint, very homogeneous. This is particularly true of the Barred Plymouth Rocks, which furnish the bulk of the statistical material with which the present investigation has to do. After October, 1902, no variety other than the Barred Plymouth Rock was used in the egg-production work. The White Wyandottes were used from 1898 to 1902, and egg records for them between these dates are available for study. On account of the small number of Light Brahmas available, together with the fact that they were dropped early in the course of the breeding experiment, they have not been included in the present investigation.

In breeding the birds from 1898 down to the present time the practice as stated in the published reports of the work has been to use each year, as mothers of the stock produced in that year, only hens which have, between November 1 of the year in which they were hatched and November 1 of the next following year, laid 160 or more eggs. The fathers of all stock raised since the breeding season of 1900 have been the sons of mothers whose production in their first laying year was 200 eggs or over. It will be seen again that this breeding practice has been such as to lead to great homogeneity of the statistical material from a biological standpoint. It is stated, however, that except in the first years of the breeding there has been no "close" inbreeding. No birds as closely related as first cousins are said to have been bred together since the first year of the breeding experiment.

The nature of the statistical records with which the present paper deals is briefly as follows: The first laying year of a hen has been arbitrarily taken to be from November 1 of the year in which she is hatched to November 1 of the following year. The "first year's egg record" of a hen, then, consists of the trap-nest record of the total number of eggs produced by that hen within such a year. Such "first-year" records constitute the basic material for Part I of this study.

Some important questions suggest themselves here. Has the "first-year" egg production any particular biological significance as compared with the egg production in any other (shorter or longer) period in the life of the bird? To what extent is there justification for taking first-year production as a measure of what might be called the total ability of a bird to produce eggs? In other words, why is annual egg production taken as the unit of the study of variation in this character? The answer to the last question is simplest: We are using annual production because it is the longest time unit for variation in egg production for which we have any extensive data available. A larger unit might, on some grounds, be desirable, but in such case as this the biometrician can only take the data as he finds them. It is obvious that the egg production in the first year can not be taken as a precise measure of the total number of eggs which hens would produce if allowed to live until natural death occurred. Whether it is a good measure or not depends on the degree to which first-year production is correlated with this unknown total possible production. No data exist from which this correlation can be precisely determined, but there are reasons to believe that if it could be evaluated it would be found to have a fairly high value. The chief of these reasons lies in the fact that in the domesticated fowl the average egg production of the first year is never equaled in any subsequent year, though with individual birds this relation may be changed. Thus, it is shown on page 65 that the mean production of 66 birds in their second laying year was but 61.7 per cent of that in their first year. That the average production falls off further in the third and subsequent years is known to be a fact. In other words, the first-year production, on the average, makes up a very considerably larger part of the unknown total production than does that of any other equal period of time. Hence we should expect it to be most highly correlated with that total.

The general conclusion which we have reached after careful consideration of the matter is that first-year production is to be regarded from the theoretical standpoint as a good measure of total possible production. It is a sufficiently large unit to include the influence of seasonal climatic changes, as well as those influences dependent on cyclical organic changes, such as, for example, original mating season, time of molting, and the like. From the practical standpoint first-year production is, for obvious reasons, in some respects the best unit which could be taken. It is highly desirable, however, that definite trap-nest records be obtained in considerable numbers for the egg production of the same birds during their entire lifetime or at least until they cease entirely to produce eggs. It is hoped that in time it will be possible to accumulate such records at the Maine station.

Another point to be noted is that the use of the term "first-year egg production" for the November-to-November laying is, in a sense, entirely arbitrary. Pullets very often begin to lay before

November 1 of the year in which they are hatched. Again, many pullets do not begin to lay until in December or later. They will not have laid a full year at the end of the following October. It is manifestly impossible to deal on any extensive scale with the actual first twelve months' egg production of each individual hen. One feasible procedure is to do as was done in this breeding investigation, namely, to take a calendar year as the unit of record, and choose the beginning of the year at a point which about averages the varying times of beginning egg production in the different individuals of the flock.

In extracting the egg records from the original record books certain complications arise which, for the sake of uniformity in the statistical treatment, we have had to decide in an arbitrary fashion. In the first place, it will always happen, of course, that death will prevent the completion of the "first laying year" by some of the birds which begin it. What shall be done with such records made incomplete by death? After careful study of the point it has been decided to omit entirely from our statistical treatment all records known to have been made incomplete by death. This is clearly the most logical method of dealing with such incomplete records which can consistently be applied. The same treatment has been given to the incomplete records of birds which were stolen during their first year. In the earlier years of the work it several times happened that birds were stolen after having completed only a part of the first year's record. All the records for stolen birds have been excluded from our statistics.

Another difficulty, and one in a sense more serious than either of those just mentioned, arises from the fact that hens do not invariably lay in the trap nests. It occasionally happens that birds will lay on the floor of the pen. Of course it then becomes impossible to connect the egg with the bird which laid it. When the study of these records was first undertaken it was for a time thought that this difficulty was a very serious one, and one which could not properly be allowed for in treating the data. Further study of the matter, however, led to the conclusion that this was not the case. In order that any conclusion regarding individual variation in egg production, or regarding the comparative production of flocks in different years or under different housing conditions, should be affected by the existence of unrecorded eggs laid on the floor, two conditions are necessary: (1) That the tendency to lay on the floor be not distributed at random (in the technical sense) among all the birds, and (2) that the total absolute amount of "floor" egg production should vary widely from year to year and in different pens. Are these conditions realized, as a matter of fact? We may discuss the two separately.

If it were a regular, constant, and undetected habit of some particular birds to lay outside the trap nests, and such birds formed a considerable portion of the flock, we could obviously draw no conclusions from trap-nest records. Such, however, appears not to be the case. Those who have had the birds in charge inform us that it has always been possible without any great difficulty to learn when a particular hen was beginning to form the habit of laying on the floor. Such hens when detected were trained, usually with comparative ease, to lay in the nests. A hen was never allowed to continue the floor-laying habit. All the available evidence and our own observations have convinced us that, could we know the birds that lay eggs outside the nests we should find them to be a random sample of the flock. That is to say, any bird is as likely as any other to lay an egg on the floor instead of in a trap nest. This being the case, the fact that there are eggs produced outside the nests will obviously not affect any conclusions respecting individual variation in egg production, if, as is the case, we deal with relatively large numbers of individuals.

Has the total number of eggs laid outside nests varied widely at different times during the period covered by the investigation, or has it been relatively constant? All the evidence that we have indicates that it has been relatively constant. Unfortunately, there exist no precise data on this point except for a single year (1904–5) out of the whole period covered by the statistics. We are informed by Mr. Walter Anderson, who has had immediate charge of the trap-nest records, that (*a*) the absolute amount of "floor" egg production has always been small, and (*b*) that in relation to the total number of eggs produced at any time the number laid on the floor has always been proportionately about the same. This means that figures for egg production based on the trap-nest records are absolutely a little too small in every case, but relatively are unaffected. It is relative figures with which we are chiefly concerned. It will obviously make no difference in our conclusions as to the comparative egg production of two years, say, if before making the comparison we add 2 per cent to the egg record for each year to cover the eggs laid on the floor.

The general conclusion, then, is that so far as the objects of the present investigation are concerned the unrecorded "floor" egg production is of no practical consequence. In the future poultry work of the Maine station an exact record will be kept of the eggs laid outside the nests.

It has further been decided to exclude from the statistical analysis the very few birds which, in the course of the trap-nesting experience of the station, have apparently laid no eggs at all in their first year. The number of such birds is so small (probably not 10 in the whole experience of the station) that it makes no significant difference in the statistical constants whether they are included or not. The specific reason for excluding such birds lies in an element of uncertainty in respect to the early records regarding them. That is, it is not possible now to be certain, in each of the cases where a bird has no record, whether the absence of record is due to the fact that she laid no eggs or to some other cause.

With this account of the general features of the statistics in hand, we may pass to the consideration of the records for particular years. We have decided to begin our discussion of the records with the data for the laying year 1899–1900; that is, with the records for birds hatched in April and May of the year 1899. The raw statistical data for this year have already been published.[a] They include records for the complete year (November 1, 1899, to November 1, 1900) for 70 Barred Plymouth Rocks and for the same number of White Wyandottes. An account of the housing and treatment of the birds for this year is given in the bulletin just referred to (pp. 31 and 32). So far as appears from the records, this laying year was in all respects a normal one. No serious accident or change of methods and management interfered in any way with the normal course of egg production.

The records for the laying year 1900–1901, that is, for birds hatched in April and May, 1900, have also been published.[b] Complete records for this laying year are available for 85 Barred Plymouth Rocks and 72 White Wyandottes. So far as may be judged from the records themselves and from the statements in Bulletin 79 (pp. 36 and 40) this may be considered to have been a normal laying year.

The egg records for the laying year 1901–2 have been published.[c] On account of lack of space relatively few pullets were carried over that winter. Complete records are available for but 48 Barred Plymouth Rocks and 33 White Wyandottes. The Barred Plymouth Rocks of that year were the first pullets sired by males bred from 200-egg-producing mothers to be tested in the trap nests. So far as we know this was a normal laying year.

The records for the years 1902–3 to 1906–7, inclusive, have never been published and were extracted by the authors of this paper from the original egg-record books in the archives of the station. In the year 1902–3, 147 of the Barred Plymouth Rock pullets tested in the trap nests completed first-year records. The egg production during this year can not be regarded as normal. The reason for this has been set forth by Professor Gowell[d] as follows:

> The pullets were hatched in April and May, and thinking to have them mostly in readiness for laying early in November, we fed them rather more beef scrap than usual

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[a] Maine Agricultural Experiment Station Bulletin 79, pp. 33–36. 1902.

[b] Loc. cit., pp. 37–40.

[c] Maine Agricultural Experiment Station Bulletin 93, pp. 72, 73. 1903.

[d] Maine Agricultural Experiment Station Bulletin 117, p. 96. 1905.

during the growing season, while they were out on the range, and before we were aware of their development they were laying—in August. They were nearly all laying heavily during September, October, and November. They were splendid birds, but almost every one of them molted completely in December, and we got very few eggs from them for more than two months. The most of the eggs secured from them were laid after the middle of January. Could they have commenced laying in October and continued for a year, molting would probably have been avoided and the showing would have been much better.

In the year 1903–4, 300 Barred Plymouth Rock pullets were tested in the trap nests. Of these 254 completed the first-year record and appear in the statistics of the present paper. The egg production of this year again can not be regarded as normal, for a reason which has been discussed by Professor Gowell (loc. cit.). Owing to a difficulty in the construction of a new house, the birds were not moved in from the range so as to begin their laying until December 6. Hence the records for 1903–4 as they appear in the statistics of the present paper are really eleven-month records instead of twelve-month records. They lack the potential contribution of the month of November, 1903, to the totals.

At the beginning of the laying year 1904–5 an experiment on the relation of the amount of floor space per bird to egg production was started. In carrying out this experiment the birds were divided into flocks of 50, 100, and 150 birds each. These were put into pens with floor space such that in the pens containing 50 and 100 birds there was 4.8 square feet of floor space per bird and in the 150-bird pens 3.2 square feet of floor space per bird. There were six 50-bird pens, and of the 300 birds which started the year in these pens 283 made complete records and appear in our statistics. There was one 100-bird pen, and 92 of these birds completed the year's record and appear in the present statistics. There was one 150-bird pen, and 140 of these birds completed the year's record and appear in the statistics. The records for this year are to be regarded as normal.

In the laying year of 1905–6 the birds tested in the trap nests were again divided into flocks of 50, 100, and 150 birds each. There were four of the 50-bird pens, and of these 200 birds 178 made complete records for the whole year and appear in the statistics of the present paper. There were two 100-bird pens, and 182 of these birds completed the year. There were also two 150-bird pens, and 275 out of the 300 birds completed the year. The laying year of 1905–6 was in nearly every respect a normal one. The only extraordinary factor which came in to interfere with the egg production during this year was a short period of sickness among the birds caused by the too free use of succulent feed. The details of this mishap have been stated by Professor Gowell[a] and need not be repeated here. The trouble occurred in April, 1906, and its effect on the egg yield is stated to have been as follows: "The egg yields were about 60 per cent of the number of birds just before the trouble began, but they were reduced to less than 10 per cent, and it was about twenty days before the birds regained their former production." This factor reduces the egg yields for the months of April and May of this year. The precise amount of this reduction would appear from the statistics not to be so great as is implied in the statement quoted. This will be more fully discussed in Part II of this study, which will deal particularly with monthly egg production.

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[a] Maine Agricultural Experiment Station Bulletin 144, p. 184. 1907.

In the laying year 1906–7 the experiments with flocks of different sizes were continued. We have records for this year of four 50-bird pens, two 100-bird pens, and two 150-bird pens. Of the 200 birds in the 50-bird pens 187 completed the year; of those in the 100-bird pens 185 completed the year; and, finally, of the 300 in the two 150-bird pens 281 have complete records for the year. In the early part of this laying year (December) a serious mishap occurred which considerably lowered the egg yields for this and the succeeding month. The matter is thus described by Professor Gowell:[a]

> Last December the roosts and walls of the roosting closets in all of the rooms but one were sprayed with two different brands of liquid lice killers which were warranted by their makers to destroy all the lice on fowl by the fumes penetrating among the feathers to the skins of the birds. The preparations were used according to directions. The roosts and woodwork near them were sprayed in the morning and left to dry until the birds went to roost. But the sprayed paint was not fully dry at that time, although it was thinned by heating before applying it. The curtains of the roosting closets were shut down at bedtime as usual and both ventilators, each of which are 3 feet long and 6 inches wide, were left wide open. Next morning it was very evident from the appearance of the birds that they had not enjoyed the night. They ate but little food during that and the succeeding three or four days and did not have their usual appetites for nine or ten days. The 700 birds were laying over 300 eggs per day before the trouble, but they laid less than 100 per day during the following week, and did not lay as many as before until twenty-four days had elapsed.
>
> Many of them molted partially, or quite fully, and these did not lay much for six or seven weeks. It is not thought that any birds died from the accident. Probably we were at fault in using the stuff in winter when it did not thoroughly dry out, as it might have done in a long, warm summer day. One pen at the end of the building was not sprayed, but the air in that room was loaded with the odor from the rest of the building, which easily found its way in around the loosely fitting door. The birds in that room fell off in their egg yields for several days, but none of them molted. Many of the birds in the sprayed rooms refused to go to roost in the closets again for several nights, until the odor had largely disappeared, while those in the unsprayed room went into their bedroom as usual.

The precise effect of this disturbance on the egg yields will be shown later in a discussion of the monthly production.

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[a] Loc. cit., p. 185.

Another point which should be noted regarding the records for 1906–7 is that they comprise the records for eleven months instead of a full year. The records were discontinued at the end of September, 1907, October of that year being entirely omitted.

From the account of the statistics of the several years included in this investigation it is evident that as they stand the data for any one year are probably not strictly comparable with those for any other year. Certainly this is true in the later years covered by the material. The statistics for each year must be treated separately, and whenever comparisons between years are instituted great caution must be exercised in drawing conclusions. It will obviously be necessary in some cases to apply corrective factors before any comparisons whatever can be made. The authors are aware that this fact constitutes the principal point at which these statistics are open to criticism, and that it is a serious defect. It should be remembered, however, when such a criticism of data like these is made, that the practical difficulties of keeping relatively constant the environmental conditions under which so many as a thousand laying hens are kept are very great. Especially is this true when the time unit of the experiments is twelve months. In nearly every case the factors which have come in to disturb the records of annual egg production, as noted above, are things which could not have been foreseen and avoided. They were accidents in the strict sense. It will be apparent in the later portions of the paper that in spite of these accidents in the several years the constants of the variation curves of egg production are very closely similar throughout the period covered by the statistics. In other words, the effect of these accidents has been decidedly more on the centering constants like the mean and the mode than upon the constants which have to do with the shape of the curve, such as, for example, the standard deviation and the skewness. On the whole, we believe that the data which we have, in spite of their shortcomings, give us a very fair picture of the true state of affairs relative to variation in annual egg production. When we come to the detailed monthly and daily statistics, which will be considered in the parts of the bulletin following the present one, these factors, which to a certain extent vitiate annual statistics, will be very much less serious, because in every case the accident has been confined to but a single month or at most two or three months.

In discussing the variation in egg production we shall consider the statistics for the Plymouth Rocks first and base the major portion of the discussion upon them. The records for the White Wyandottes will be taken up farther on in a separate section of the paper.

STATISTICAL METHODS USED.

In dealing with these egg-record statistics obviously the first thing to be done is to get the data in the form of frequency distributions. We have done this for each year's records of each set of pens (50, 100, and 150 birds) without grouping data in any way. These ungrouped frequency distributions, which form the basic raw material of the first part of this study, are given in detail in Appendix I, Tables I, II, and III. A glance at these distributions will indicate at once that the range of variation in egg production is very considerable. It is so great, in fact, as to make analytical treatment necessary if we are to form any adequate idea of variation in this character.

In this investigation we have made use of the ordinary methods of biometrical analysis. Summary accounts of these methods have been given by Elderton,[a] C. B. Davenport,[b] and E. Davenport.[c] For more detailed accounts the reader is referred to the memoirs of Pearson on the subject which have appeared in (*a*) the Philosophical Transactions of the Royal Society during the period from 1895 to 1905; (*b*) Biometrika; and (*c*) the Draper's Company Research Memoirs of the Department of Applied Mathematics of University College, London. In view of the existence of the treatises referred to it will not be necessary here to go into a general account of biometrical methods. It is, however, desirable to call attention to certain specific modes of treating these egg-production statistics which we have adopted.

The problem of grouping the material may be first considered. From the extent of the range it is obviously necessary that some grouping be resorted to in order to get a smooth frequency distribution covering the whole range of variation in annual egg production (more than 200 eggs). If the data were not grouped it would be necessary to have records of very many individuals, probably hundreds of thousands. With the smaller numbers which practical considerations make the only possible ones, it is clearly necessary that the data be grouped. When grouping such data the usual rule followed in biometrical work is to make as many classes as will give a fairly smooth distribution without too many classes having zero frequency. Obviously if the class units are sufficiently large all frequency distributions will be reduced to very much the same form. Only experience can decide what is the most appropriate value to take for the class unit in any specific case. After studying all the data on variation in egg production we have come to the conclusion that a class unit of 15 eggs is probably as satisfactory as any which could be taken. In adopting this unit we have set the class limits at the same points in the case of each distribution; that is to say, the first class includes birds laying from 0 to 14 eggs inclusive; the next class, birds laying from 15 to 29 eggs inclusive, and so on. The procedure sometimes followed of taking different limits for the class unit in the case of each frequency distribution, and subsequently treating these distributions as if they were in every way strictly comparable, is obviously not a logical one.

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[a] Elderton, W. P. Frequency Curves and Correlation. London, 1907. Pp. xiii and 172.

[b] Davenport, C. B. Statistical Methods with Special Reference to Biological Variation. Second edition. New York, 1904. Pp. viii and 223.

[c] Davenport, E. The Principles of Breeding. Boston, 1907. Pp. xiii and 727.

In deducing the moments from the grouped material we have in each case used Sheppard's corrections.[a] It will appear further on in the paper that the problem of getting satisfactory theoretical curves to graduate these statistics of egg production is an extremely difficult one. It occurred to us that possibly better success in the graduation of the curves might be had by using raw instead of corrected moments. Actual trial, however, showed that somewhat worse instead of better results were obtained when the raw moments were used. On the whole, this is what is to be expected on theoretical grounds, as will be apparent when the grouped frequency distributions are examined. Our material is grouped in rather large units, and at the same time we have apparently fairly close approximation to high contact at both ends of the range. These conditions, of course, indicate that Sheppard's corrections are demanded.

In deducing constants from the ungrouped material we have calculated the mean and the median by ordinary arithmetical methods. In calculating standard deviations in these cases we have used the method of moments rather than the method of calculating from the formula $\sigma^2 = \frac{S(x^2)}{n}$, where x denotes deviation from the mean. In calculating the mode in the case of the ungrouped frequency distributions, use has been made of the approximate relation:

$$\text{Mean to mode} = 3 \times \text{(mean to median)},$$

the median of the curve lying between the mean and the mode. This approximation to the position of the mode was first worked out empirically by Pearson[b] and found to give reasonably close values in most cases. Recently Charlier[c] has derived this relation directly in his treatment of a certain type of frequency curve. He shows definitely why this approximation to the mode must give a fairly close value in all cases where the frequency curve is not too widely divergent from the normal curve of errors. In order to determine for the class of curves with which we are here dealing how good this approximation to the mode is, we have calculated for six curves, (*a*) the true value of the mode from the moments, by the usual general formula,[a]

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[a] Sheppard, W. F. Biometrika, Vol. V, pp. 450–459. 1907.

[b] Cf. Pearson, K. Biometrika, Vol. I, pp. 260, 261. 1902.

[c] Charlier, C. V. L. Researches into the Theory of Probability. Meddelanden från Lunds Astronomiska Observatorium, Serie II, No. 4, Kongl. Fysiografiska Sällskapets Handlingar, Bd. 16, pp. 1-51. 19 fig. Lund, 1906.

$$d = \frac{1}{2}\,\frac{\sqrt{\mu_2}\,\sqrt{\beta_1}\,(\beta_2+3)}{5\beta_2-6\beta_1-9}$$

and (*b*) the approximate value of the mode by the method under discussion. The results are shown in the following table:

Year and group.	True mode.	Mode by approximate method.	Difference.
1903	139.20	143.25	−4.05
1904, 50-bird pens	149.14	148.30	−0.84
1905, 50-bird pens	149.48	149.88	−0.40
1905, 100-bird pens	135.00	133.00	+2.00
1906, 50-bird pens	123.21	120.44	+2.77
1906, 150-bird pens	103.73	105.89	−2.16

When it is remembered that the probable errors of the centering constants (mean and median) are in these curves of about the magnitude ±2, it is apparent that the approximation gives values as close to the true mode as could reasonably be expected.

Having determined the mode in the manner indicated, in the case of the ungrouped material, the distance from mean to mode was used to find the skewness by the following relation:

$$\text{Skewness} = \frac{\text{Distance from mean to mode}}{\text{Standard deviation}}$$

Respecting the probable errors of the various constants discussed, the following should be said. The probable error of the mean was calculated from the usual formula,

$$P.\ E._{mean} = 0.67449\frac{\sigma}{\sqrt{n}}$$

using Gibson's tables.[b] Theoretically, in the case of the grouped material, where Sheppard's corrections are applied to the moments, the uncorrected value of σ should be used in this formula.[c] But practically, with the very large values of σ with which we have here to do, and the consequent large absolute values of the probable errors, it makes no difference, to the number of decimal places tabulated in the probable errors, whether the corrected or uncorrected value is used. We have consequently used the corrected values to save labor. The probable error of the median is given by Sheppard[a] as follows:

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[a] Pearson, K. Philosophical Transactions of the Royal Society, vol. 198 A, p. 277. 1902.

[b] Gibson, W. Biometrika, Vol. IV, pp. 385–393. 1906.

[c] Cf. Sheppard, W. F. Biometrika, Vol. V, p. 455. 1907.

$$P.\ E._{median} = 0.84535 \frac{\sigma}{\sqrt{n}}$$

For the sake of economy in calculation we have made use of the obviously simpler relation:

$$P.\ E._{median} = 1.25332 \times P.\ E._{mean}$$

In the case of the probable error of the standard deviation it has recently been pointed out by the writer[b] that caution must be exercised in using the formula usually given, viz:

$$P.\ E.\ \sigma = 0.67449 \frac{\sigma}{\sqrt{2n}} \text{ - - - - - - - - - - - - - - - - - } \text{(i)}$$

When curves deviate much from the normal curve of errors $P.\ E.\ \sigma$ by this formula may be seriously in error. Resort should be had in all cases of importance to the general formula

$$P.\ E.\ \sigma = 0.67449 \sqrt{\frac{\mu_4 - \mu_2^2}{4\mu_2} \Big/ n} \text{ - - - - - - - - - - - - - - } \text{(ii)}$$

which for convenience in computation may be written

$$P.\ E.\ \sigma = \chi_1 \sqrt{\frac{\mu_4 - \mu_2^2}{4\mu_2}}$$

where χ_1 is the value $0.6744898 / \sqrt{n}$ tabled by Miss Gibson (loc. cit.). In the present investigation we have made it a rule to calculate this probable error by equation (ii) in every case where it was necessary for some other reason to determine the value of μ_4. In all other cases equation (i) was used. In the tables it will be specifically indicated which formula was used in each particular case.

The usual formula for the probable error of the coefficient of variation V,

$$P.\ E._V = \frac{.067449}{\sqrt{2n}} \left[1 + 2\left(\frac{V}{100}\right)^2 \right]^{\frac{1}{2}}$$

was used throughout.

In the case of the skewness the question of the proper value of the probable error is a difficult one. It has been shown by Pearson and Filon[c] that the probable error of this constant has a different value for each different type of frequency curve. A maximum limit, however, is always given by the value in the case of the normal curve, i. e.,

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[a] Sheppard, W. F. Philosophical Transactions of the Royal Society, vol. 192 A, pp. 101–167. 1898.

[b] Pearl, R., Biometrika, Vol. VI, pp. 112–117. 1908.

[c] Pearson, K., and Filon, L. N. G. Philosophical Transactions of the Royal Society; vol. 191 A, pp. 229–311. 1898.

$$P.\ E._{Sk.}=0.67449\sqrt{\frac{3}{2n}}$$

The authors cited point out (loc. cit., p. 271, footnote) that a very close approximation of the probable error of the skewness generally is given by the relation

$$P.\ E._{Sk.}=0.67449\sqrt{\frac{3}{2n}}\frac{1}{\sqrt{\{1+3(Sk.)^2\}}}$$

This formula we have used throughout, first putting it in the somewhat simplified form

$$P.\ E._{Sk.}=\frac{1.7320508\chi_2}{\sqrt{\{1+3(Sk.)^2\}}}.$$

where χ_2 is the function tabled by Miss Gibson (loc. cit.).

All the computations in this investigation have been carried out with the aid of a large Brunsviga arithmometer and an adding machine. All possible precautions have been taken to exclude arithmetical errors in the work. It is the intention to publish all the raw material which was available to the authors (in the present or later parts) of this paper, so that it will be possible for any interested persons to check up the computations.

VARIATION IN EGG PRODUCTION IN BARRED PLYMOUTH ROCKS.

Turning now to the discussion of the results of the work, we have first the grouped frequency distributions for variation in first-year egg production in Barred Plymouth Rock pullets during a period of eight years set forth in Table 1. In this table are given both the absolute frequencies and the frequencies per cent for each year.

TABLE 1.—*Frequency distributions for variation in first-year egg production, Barred Plymouth Rocks.*

Year and group.	Annual egg production.																	Total.
	0–14.	15–29.	30–44.	45–59.	60–74.	75–89.	90–104.	105–119.	120–134.	135–149.	150–164.	165–179.	180–194.	195–209.	210–224.	225–239.	240–254.	
1899–1900:																		
Absolute frequency			3	2	4	4	4	2	10	11	9	12	6	1	1	1		70
Percentage frequency			4.29	2.86	5.71	5.71	5.71	2.86	14.29	15.71	12.86	17.14	8.57	1.43	1.43	1.43		100.00
1900–1901:																		
Absolute frequency		1		4	4	2	6	7	6	15	5	14	12	7	1	1		85
Percentage frequency		1.18		4.71	4.71	2.35	7.06	8.24	7.06	17.65	5.88	16.47	14.12	8.24	1.18	1.18		100.03
1901–1902:																		
Absolute frequency					1	1	2	8	4	1	11	8	3	5	3		1	48
Percentage frequency					2.08	2.08	4.16	16.67	8.32	2.08	22.92	16.67	6.25	10.42	6.25		2.08	99.98
1902–1903:																		
Absolute frequency		2		1	5	8	17	18	17	26	17	18	9	2	6	1		147
Percentage frequency		1.36		.68	3.40	5.44	11.56	12.24	11.56	17.69	11.56	12.24	6.12	1.36	4.08	.68		99.97
1903–1904:																		
Absolute frequency	7	5	5	10	10	20	24	29	52	37	29	16	8	2				254
Percentage frequency	2.76	1.97	1.97	3.94	3.94	7.87	9.45	11.42	20.47	14.57	11.42	6.29	3.15	.79				100.01
1904–1905:																		
50-bird pens—																		
Absolute frequency	3	3	14	7	9	15	16	39	24	40	33	28	16	25	7	3	1	283
Percentage frequency	1.06	1.06	4.95	2.47	3.18	5.30	5.65	13.78	8.48	14.13	11.66	9.89	5.65	8.83	2.47	1.06	.35	99.97
100-bird pens—																		
Absolute frequency		2	4	1	3	8	10	11	5	7	11	11	8	9	2			92
Percentage frequency		2.17	4.35	1.09	3.26	8.70	10.87	11.96	5.43	7.61	11.96	11.96	8.70	9.78	2.16			100.01
150-bird pens—																		
Absolute frequency	7	6	3	9	6	15	10	18	12	10	19	11	6	6	2			140
Percentage frequency	5.00	4.29	2.14	6.43	4.29	10.71	7.14	12.86	8.57	7.14	13.57	7.86	4.29	4.29	1.43			100.01
1905–1906:																		
50-bird pens—																		
Absolute frequency			1	2	4	9	13	25	24	22	32	17	20	9				178
Percentage frequency			.56	1.12	2.25	5.06	7.30	14.04	13.48	12.36	17.98	9.55	11.24	5.06				100.00
100-bird pens—																		
Absolute frequency	1	3	3	3	8	14	17	26	25	23	27	16	12	3			1	182
Percentage frequency	.55	1.65	1.65	1.65	4.40	7.69	9.34	14.29	13.74	12.64	14.84	8.79	6.59	1.65			.55	100.02
150-bird pens—																		
Absolute frequency	1	1	4	10	21	23	35	46	40	35	25	19	8	6	1			275
Percentage frequency	.36	.36	1.45	3.64	7.64	8.36	12.73	16.73	14.55	12.73	9.09	6.91	2.91	2.18	.36			100.00
1906–1907:																		
50-bird pens—																		
Absolute frequency	2	2	5	5	9	16	30	39	26	21	19	12	1					187
Percentage frequency	1.07	1.07	2.67	2.67	4.81	8.56	16.04	20.86	13.90	11.23	10.16	6.42	.53					99.99
100-bird pens—																		
Absolute frequency	4		8	11	7	25	29	25	30	20	11	10	5					185
Percentage frequency	2.16		4.32	5.95	3.78	13.51	15.68	13.51	16.22	10.81	5.95	5.41	2.70					100.00
150-bird pens—																		
Absolute frequency	10	8	8	15	29	32	48	39	36	25	18	6	5		2			281
Percentage frequency	3.56	2.85	2.85	5.34	10.32	11.39	17.08	13.88	12.81	8.90	6.40	2.14	1.78		.71			100.01

The percentage distributions for 1903, for the 50-bird pens of 1904, the 50, 100, and 150 bird pens of 1905, and the 50, 100, and 150 bird pens of 1906 are shown graphically in figures 1 to 8, inclusive. Of the other distributions the majority involve so few individuals relatively that they give rather irregular polygons. On this account, and since the general form in all is very similar to that of the polygons which are shown graphically, it will not be necessary to figure them separately.

From the data given in Table 1 and the diagrams we note at once the following general characteristics of variation in egg production:

1. The distribution of variation is not usually symmetrical about the center or type of egg production. The distributions nearly all show some degree of asymmetry or skewness. Further, this skewness is obviously negative in all cases—that is, the distributions tail off more gradually toward the side of low egg production.

2. The range of variation in egg production is very considerable, even in a stock so closely selected to type as this has been. The observed range extends from an egg production of zero to one of nearly 250. The manner in which this great range is covered is perhaps even more strikingly shown in the tables of Appendix I than in Table 1.

3. The distributions generally have more than one observational mode or peak. This fact, however, is probably not to be interpreted as meaning that the normal egg-production variation curve is a multimodal one. It is in all probability merely a result of random sampling with respect to a character having a great range of variation, when, furthermore, each sample contains only a relatively small number of individuals. The general form of the frequency distributions would indicate that the variation in the character is of the usual unimodal skew type. This point, however, will be more particularly discussed later on in the paper, when the evidence from the analytical constants is at hand.

4. Not only is the range of variation in egg production great, but also the absolute amount of variation in the character, as indicated by the "scatter" of the distributions, is relatively large. This will be made clearer by the constants of variation, to the examination of which we may next turn.

In Table 2 are given the values of the chief physical constants of the frequency distributions of Table 1, together with their probable errors. The methods by which the calculations were made have been described in the previous section. Six constants are included in the table. A brief examination of their meaning may be useful. The first of the constants tabled—the mean or average annual egg production—needs no explanation. The median (the second constant tabled) is the value at which the flocks divide into two equal parts in regard to egg production. Thus, in 1902–3 one-half of the birds laid more than 137.5 eggs and one-half laid fewer than that number. The mode is that amount of annual egg production which is exhibited by the largest number of birds. It is the "fashionable" egg production. For example, in 1902–3 more hens laid 139.53 eggs in the year than laid any other single number, either greater or less. The standard deviation is a measure of absolute variation; in the present instance it expresses the degree of variation in annual egg production in terms of eggs. It is a measure of the "spread" or "scatter" of the frequency distribution. The coefficient of variation is a relative measure of variation. It is the percentage of the standard deviation in the mean. The skewness is the measure of the degree to which the frequency curve is asymmetrical. A positive skewness means that the curve tails off more gradually toward large values than toward small values of the character under discussion, while a negative skewness means that, as in the present cases, the curve tails off more gradually toward the small values of the character. With positive skewness the mean is greater than the mode, while with negative skewness the reverse relation holds.

In the last three lines of Table 2 are given the weighted mean values of each constant for the years 1904–5, 1905–6, and 1906–7, respectively. In each of these years we have data for flocks of 50, 100, and 150 birds each. In order to get a single value which shall be in a measure representative of each constant for each of these years the only feasible procedure is to take a weighted mean of the values of the particular constants for each of the three flocks. This we have done. We have weighted the several flock constants in each case with the number of birds they involve, as shown in Table 1. A single example worked out in extenso will make plain just how these weighted values are obtained:

1905–6, 50-bird pens: Mean 140.31 × 178 = 24,975.18
1905–6, 100-bird pens: Mean 127.50 × 182 = 23,205.00
1905–6, 150-bird pens: Mean 119.43 × 275 = 32,843.25
Sums = 635 and 81,023.43

81,023.43 ÷ 635 = 127.60 = "weighted mean" egg production in year 1905–6.

TABLE 2.—*Constants of variation in annual egg production, Barred Plymouth Rocks.*

Laying year and group.	Mean.[a]	Median.	Mode.	Standard deviation.	Coefficient of variation.	Skewness.
1899-1900	136.36±3.55	142.00±4.45	153.29	44.03±2.51	32.29±2.02	−0.384±0.082
1900-1901	143.44±3.29	146.25±4.12	151.88	45.02±2.33	31.38±1.78	− .188± .081
1901-2	155.58±3.79	158.50±4.75	164.33	38.94±2.68	25.03±1.83	− .225± .104
1902-3	136.48±2.19	137.50±2.74	139.54	39.24±1.55	28.82±1.22	− .078± .067
1903-4	117.87±1.75	126.33±2.20	139.20	[c]41.43±1.31	35.14±1.17	− .515± .059
1904-5:						
50-bird pens	134.60±1.98	139.17±2.49	149.14	[c]49.49±1.29	36.77±1.17	− .294± .044
100-bird pens	138.61±3.47	141.00±4.35	155.78	[c]49.41±2.46	36.98±2.07	− .449± .068
150-bird pens	114.54±3.02	117.00±3.79	121.93	[c]53.04±2.38	46.31±2.23	− .139± .068
1905-6:						
50-bird pens	140.31±1.81	143.50±2.26	149.48	[c]35.75±1.11	25.48±0.97	− .256± .052
100-bird pens	127.50±2.03	129.38±2.54	135.00	[c]40.59±1.49	31.84±1.23	− .185± .056
150-bird pens	119.43±1.54	[b]118.86±1.93	120.07	[c]37.88±1.01	31.72±1.00	− .017± .050
1906-7:						
50-bird pens	114.16±1.74	116.25±2.18	123.21	[c]35.22±1.29	30.91±1.18	− .263± .055
100-bird pens	106.53±1.92	[b]110.75±2.41	109.55	[c]38.71±1.81	35.54±1.39	− .016± .061
150-bird pens	101.08±1.64	102.50±2.06	103.73	[c]40.87±1.16	40.43±1.32	− .065± .050
1904-5, weighted mean	128.97	133.47	142.93	50.44	39.40	− .280
1905-6, weighted mean	127.60	128.77	132.59	38.06	30.01	− .132
1906-7, weighted mean	106.94	108.77	110.96	38.64	36.32	− .108

[a] Beginning with the year 1902-3, the means (and also the other constants except the medians) are calculated from the grouped frequency distributions of Table 1, instead of from the ungrouped distributions given in the appendix. This leads to slightly different values than are obtained if one calculates directly from the ungrouped material. The differences, however, are always very small, and are not sensible in comparison with the probable errors of the constants. In passing it should be said that on theoretical grounds there is every reason to suppose that the means from the grouped figures represent more nearly the unknowable true means than do those from the ungrouped material.

[b] The failure of the median in these cases to fall between the mean and the mode arises from the fact that the skewness of these curves is very small. Consequently mean, median, and mode very nearly coincide. Each is subject to a considerable probable error, great enough indeed so that twice the range included within the probable error of any one of these constants includes the other two within its limits.

[c] These probable errors were calculated by the formula involving μ_4. (Cf. p. 23, supra.)

Attention may first be called to certain general points brought out by the constants in this table, and then turned to the discussion of specific problems, for which the table furnishes data. We note first that the mean or average egg production ranges in amount between about 100 eggs (150-bird pen, 1906-7) and 156 eggs (1901-2). The median and the mode are in every case larger than the mean, indicating, as does also the last column of the table, that all these egg-production variation curves are negatively skew. The amount of variation in annual egg production is large both absolutely and relatively. The lowest coefficient of variation in the table is 25.03 per cent (1901-2). Even this is a distinctly large coefficient, when compared with what has been found for various characters in other organisms than the domesticated fowl. The values of the constants measuring variation obtained in this case indicate that egg production is to be classed, so far as variation is concerned, with purely physiological characters. It has been pointed out by the writer[a] that in the case of man characters which in general may be regarded as strictly physiological (even though they may be, as in the present case, measured in morphological units) vary much more than do such morphological characteristics as bone measurements and the like. This point has recently been confirmed by Kellicott[b] in his study of variation in the toad. We hope later to have quantitative data regarding variation in other characters of the domestic fowl, so that direct comparison of various characters and organs in respect to variation may be made.

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[a] Pearl, R. Biometrika, Vol. IV, pp. 31-36. 1905.

[b] Kellicott, W. E. Journal of Experimental Zoology, Vol. IV, pp. 576-614. 1907.

It is of interest to compare these results on variation in egg production with the results of other workers regarding variation in fertility and fecundity in other organisms. In Table 3 we have collected the existing data, from which such comparisons may be made. We have included data on variation in number of seeds produced in a plant, this being obviously a measure of gross fertility in such a case.

TABLE 3.—*Constants of variation in fertility and fecundity in various organisms.*

Subject.	Character.	Coefficient of variation.	Skewness.	Authority.
Nelumbium luteum	Number of seeds	17.445	+0.0164	Pearl.[a]
Poland-China swine	Size of litter	27.411	+ .0701	Surface.[b]
Duroc-Jersey swine	do	25.997	+ .0539	Surface.[b]
Horse	Fecundity [c]	24.771	− .1286	Pearson.[d]
Man	Number of children	48.41	+ .0802	Powys.[e]
Domestic fowl	Annual egg production	[f] 34.21	[f] − .205	This paper.

[a] American Naturalist, Vol. XL, pp. 757-768. 1906.

[b] Reductions of data given by Rommel (Bureau of Animal Industry Circular No. 95). A paper giving a detailed account of these reductions is now in press.

[c] Fecundity in this case means the fraction which the actual number of offspring arising from a given number of coverings is of the possible number of offspring under the circumstances.

[d] Biometrika, Vol. I, pp. 289-292. 1902. Actually only the moments of this fecundity curve are given at the place cited. From the moments we have calculated the coefficients of variation and the skewness.

[e] Biometrika, Vol. V., p. 251. 1905.

[f] Weighted mean value of the constant for the whole period 1899-1900 to 1906-7, inclusive. The weighting is in proportion to the number of birds involved in each year.

Further data for man might be included in this table, but that is hardly necessary, as the example given of a human fertility curve is based on very extensive data and may be regarded as typical. It is clear from the table that these egg-production curves are in no way exceptional in regard to the degree of variation which they exhibit. It appears to be generally the case that fecundity, fertility, and closely allied characters are highly variable. There would seem to be a tendency for the coefficients measuring variation in these characters to be above a value of 20 per cent. In general it may be said that, so far as indicated by the present data, the domestic fowl exhibits a relative degree of variation in annual egg production distinctly less than that shown in normal human stocks in respect to size of family, and rather greater than that in Thoroughbred brood mares in respect to fecundity.

In Table 3 have also been included comparative data respecting the skewness of variation in the several characters enumerated. It is evident at once that there is even less uniformity in this particular than in the relative amount of variation. Even the sign of the skewness is not the same in all cases. In general the degree of skewness is small. The only cases in which the direction of the asymmetry of the distribution is negative are those of fecundity in brood mares and egg production in fowls. Human fertility curves all agree in showing a distinct positive skewness. It was at first thought that the negative skewness of the egg-production curves might owe its origin to the practice which has been followed of selection for high production. It seems improbable, though, that this is the case, because, as indicated in the last column of Table 2, environmental conditions appear to have a great deal to do with the shape of the curves of variation in egg production.

ANALYTICAL DISCUSSION OF VARIATION IN EGG PRODUCTION.

Having now considered the general facts respecting variation in annual egg production, we may next turn our attention to the more complete mathematical analysis of the variation curves, using the methods of Pearson.[a] We have carried out the analysis in detail and fitted curves to the following distributions given in Table 1: 1903–4; 1904–5, 50-bird pens; 1905–6, 50, 100, and 150 bird pens; 1906–7, 50, 100, and 150 bird pens. The other distributions involve so few individuals as to make their detailed treatment unprofitable. The analytical constants are exhibited in Table 4. The moments are given in terms of the unit of grouping, which in each case is equal to 15 eggs.

TABLE 4.—*Analytical constants of variation in annual egg production.*

Constant.	1903–4.	1904–5, 50-bird pens.	1905–6.			1906–7.		
			50-bird pens.	100-bird pens.	150-bird pens.	50-bird pens.	100-bird pens.	150-bird pens.
N	254	283	178	182	275	187	185	281
μ_2	7.6269	10.8868	5.6818	7.3233	6.3761	5.5117	6.6601	7.4221
μ_3	− 14.6883	− 13.3924	− 3.8863	− 7.0879	− .4478	− 6.2369	− 4.5912	− 3.0085
μ_4	187.6675	318.7131	81.2274	168.5017	111.2316	97.7818	126.9814	165.2723
β_1	.4860	.1390	.0823	.1279	.0008	.2323	.0714	.0221
$\sqrt{\beta_1}$	.6971	.3728	.2869	.3577	.0278	.4820	.2671	.1488
β_2	3.2262	2.6890	2.5161	3.1419	2.7360	3.2188	2.8627	3.0002
β_2-3	+ .2262	− .3100	− .4839	+ .1419	− .2640	+ .2188	− .1373	+ .0002
κ_1	− 1.0055	− 1.0389	− 1.2149	− .0999	− .5303	− .2594	− .4886	− .0660
Skewness	− .5148	− .2937	− .2564	− .1848	− .0171	− .2631	− .0160	− .0650
d . . . Eggs	21.33	14.53	9.17	7.50	.65	9.26	.62	2.66
Standard deviation, eggs	41.43	49.49	35.75	40.59	37.89	35.22	38.71	40.87
Mean . . . Eggs	117.87	134.60	140.31	127.50	119.43	113.94	108.93	101.08
Mode . . . do	139.20	149.14	149.48	135.00	120.07	123.21	109.55	103.73
Range . . . do	331.82	328.21	221.29	1265.08	344.88	631.22	599.98	. . . .
+end of range . . do	194.41	248.18	208.55	313.77	291.87	226.11	358.93	. . . .
−end of range . . do	−137.41	− 80.02	12.74	−951.31	− 53.01	−405.11	−141.06	. . . .
y_0 per cent	13.47	11.46	15.32	14.86	14.49	17.19	15.18	14.64
P. E. $\sqrt{\beta_1}$ [b]	± .1037	± .0962	± .1238	± .1224	± .0996	± .1208	± .1214	± .0986
P. E. β_2 [b]	± .2074	± .1964	± .2476	± .2448	± .1992	± .2416	± .2428	± .1972
P. E. skewness [b]	± .0518	± .0491	± .0619	± .0612	± .0798	± .0604	± .0607	± .0493

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[a] Mathematical Contributions to the Theory of Evolution. II.—Skew Variation in Homogeneous Material. Philosophical Transactions of the Royal Society, vol. 186 A, pp. 343–414. 1895. Math. Contr., etc. X.—Supplement to a Memoir on Skew Variation. *Ibid.*, vol. 197 A, pp. 443–459. 1901.

[b] These are the probable errors in the case of the normal curve, and are introduced to show the degree to which the present curves deviate from normality.

Examining first the criterion $\kappa_1 = 2\beta_2 - 3\beta_1 - 6$, we note that it is in every case negative. This indicates that unless $\sqrt{\beta_1} = 0$ within the limits imposed by its probable error the curves demanded are of Pearson's Type I, with range limited in both directions, and skewness. From the value of $\sqrt{\beta_1}$, given in the table, we conclude that the first four of the distributions, and also that for the 50-bird pens in 1906–7, fulfill the conditions for a Type I curve. The three remaining distributions have a very small (practically insignificant) skewness. Consequently $\sqrt{\beta_1}$ approaches zero closely in its value in these cases, and is in each instance not significant in comparison with its probable error. Hence, the conclusion is that a symmetrical curve must be used to graduate these three distributions. This limits the choice to Pearson's Type II, a symmetrical curve with the range limited at both ends, on the one hand, or to the normal or Gaussian curve of errors, symmetrical but of unlimited range, on the other hand. The criteria which indicate the proper choice in such a case are, first, that if κ_1 be negative (as is the case with all of our three curves) it indicates a Type II curve, and second, that if β_2 be significantly different from 3, again a Type II curve is indicated. In our three distributions $\beta_2 - 3$ can not in any single case be asserted to be significant in comparison with the probable error of β_2. In the case of the 1905–6 150-bird pen distribution the probability is that $\beta_2 - 3$ is significant. There is little doubt that in this case we shall get a better graduation with a Type II curve than with a normal curve. Accordingly, such a curve has been fitted in this distribution. In the case of the other two distributions we should undoubtedly get sensibly as good graduations with either Type II or normal curves. We have used Type II in the case of the 100-bird pen curve (1906–7) and the normal curve in the case of the 150-bird pen distribution (1906–7).

The equations to the eight curves follow.

1903–4:

$$y = 34.22\left(1 + \frac{x}{18.4410}\right)^{6.9897}\left(1 - \frac{x}{3.6804}\right)^{1.3950}$$

1904–5, 50-bird pens:

$$y = 32.42\left(1 + \frac{x}{15.2774}\right)^{4.8540}\left(1 - \frac{x}{6.6032}\right)^{2.0980}$$

1905–6, 50-bird pens:

$$y = 27.42\left(1 + \frac{x}{9.1157}\right)^{3.3313}\left(1 - \frac{x}{4.7876}\right)^{1.7496}$$

1905–6, 100-bird pens:

$$y = 27.05\left(1 + \frac{x}{72.4209}\right)^{102.1468}\left(1 - \frac{x}{11.9179}\right)^{16.8097}$$

1905–6, 150-bird pens:

$$y = 39.86\left(1 - \frac{x^2}{132.1586}\right)^{8.8636}$$

1906–7, 50-bird pens:

$$y = 32.14\left(1 + \frac{x}{35.2214}\right)^{36.7812}\left(1 - \frac{x}{6.8600}\right)^{7.1698}$$

1906–7, 100-bird pens:

$$y = 28.08\left(1 - \frac{x^2}{277.7664}\right)^{19.3530}$$

1906–7, 150-bird pens:

$$y = 41.15\, e^{-0.0074x^2}$$

The frequency distributions and their fitted curves are shown graphically in figures 1 to 8, inclusive. In drawing these variation curves the frequencies have all been reduced to percentages. Hence, since the abscissal units are taken equal, all the curves have equal areas, and any given ordinates are directly comparable in the different diagrams.

It is clear from these figures that the curves give graduations of the data which are on the whole very good. They are quite as satisfactory as could reasonably be expected with such relatively small numbers in the observational series and the consequent irregularity of the polygons.

From Table 4 and the diagrams we note—

1. That the skewness or asymmetry of the variation curves, while in all but three cases distinct and significant, is in none of these curves extreme. Variation in egg production tends to approach the Gaussian type of distribution rather closely. The uniform tendency for the skewness in these curves to be in the negative direction when it exists at all is evident from the diagrams.

2. There is no uniform tendency for these ovulation curves to be either leptokurtic or platykurtic (that is, more or less peaked than the normal curve of equal standard deviation). In four out of the eight curves the sign of $\beta_2 - 3$ is positive, in the remainder negative. The deviation from the condition of mesokurtosis is in no case great, however. In view of the magnitude of the probable errors of β_2, it is impossible to assert that any of the deviations from mesokurtosis are certainly significant. In the case of the 1905–6 50-bird pen curve the value of the kurtosis $\beta_2 - 3$ is probably significant. In all the other cases the probability is in the other direction.

3. The total range is clearly overestimated in all but one case (1905–6, 50-bird pen), and in several of the curves this exaggeration of the range is very great. A total range of 328 or 332 or 345, while rather large, is not absolutely impossible theoretically. But when we come to a range of 1,265 eggs for the individual variation in egg

production within a year, it is clear that the exaggeration has gone far beyond the limits of what we must regard as possible. In spite of the great overestimation of the total range it will be observed that the upper (+) end of the range in every case has a value which is theoretically possible. While the production of over 300 eggs in a year by an individual hen has never been recorded so far as we are aware, it still would be very difficult to prove that such an event is theoretically impossible. The really serious difficulty with the range,

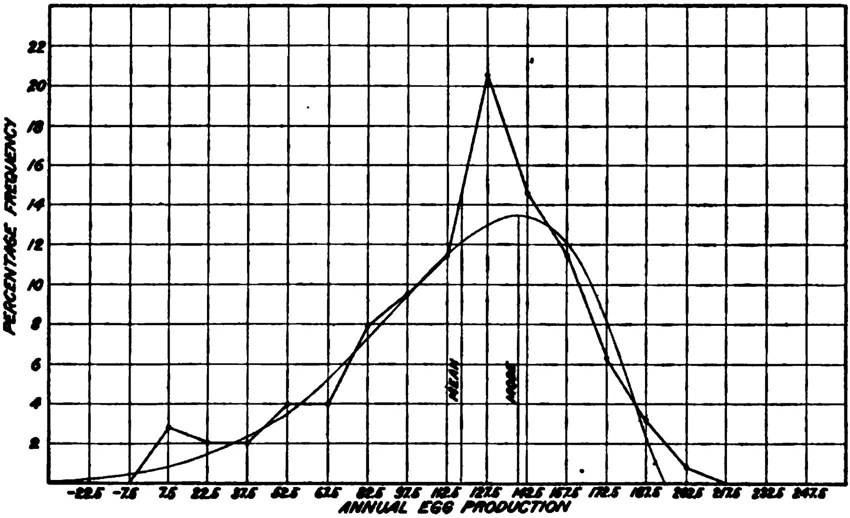

FIG. 1.—Variation in annual egg production, 1903-4.

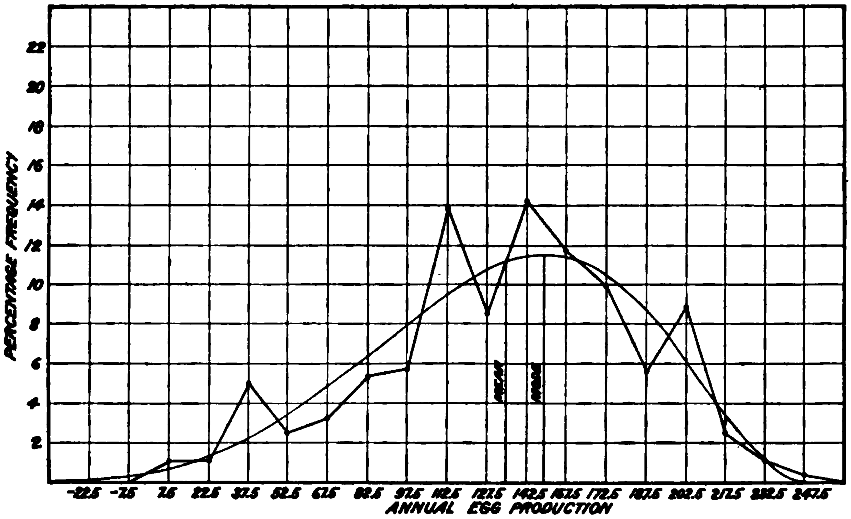

FIG. 2.—Variation in annual egg production, 1904-5.

as given by the curves, lies in the location of the lower (−) range end. In only one of the eight curves (1905–6, 50-bird pen) does the lower range end have a value which is physically possible. It is obvious

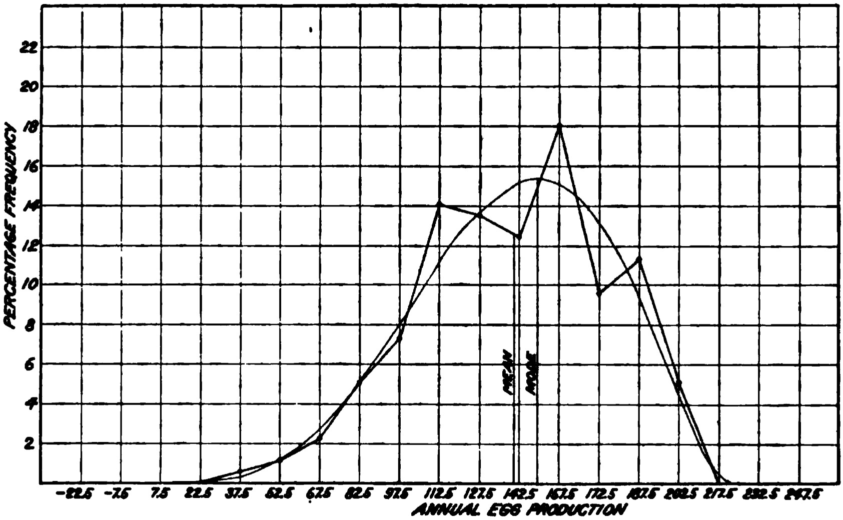

FIG. 3.—Variation in annual egg production, 1905–6, 50-bird pens.

that no hen is capable of laying fewer than no eggs at all in a year, yet, with the single exception noted, the lower range end has a negative value in every case.

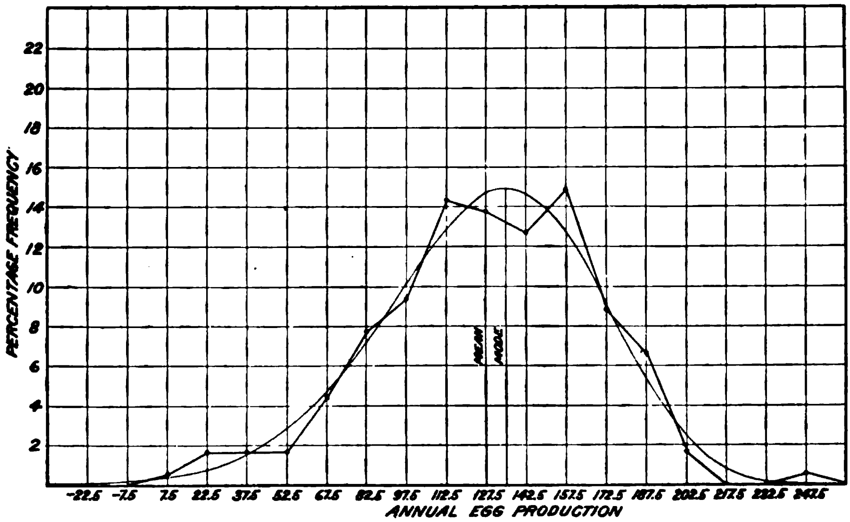

FIG. 4.—Variation in annual egg production, 1905–6, 100-bird pens.

The nearly uniform failure of the fitted curves to give reasonable estimations of the range limits of variation in egg production is remarkable. Anyone who has had any large experience with Pearson's limited range curves knows that they almost never lead to impossible estimations of the range ends. We have given the matter very careful study in the present case, and while we are able easily to understand and explain the results we get with these curves, we have not been able to modify them in any way so as to get a better representation of the actual range by the theoretical. It occurred to us that possibly by using the unmodified moments in the place of those corrected by Sheppard's formulæ we might get a better estimation of the range. Trial, however, proved this not to be the case. In these

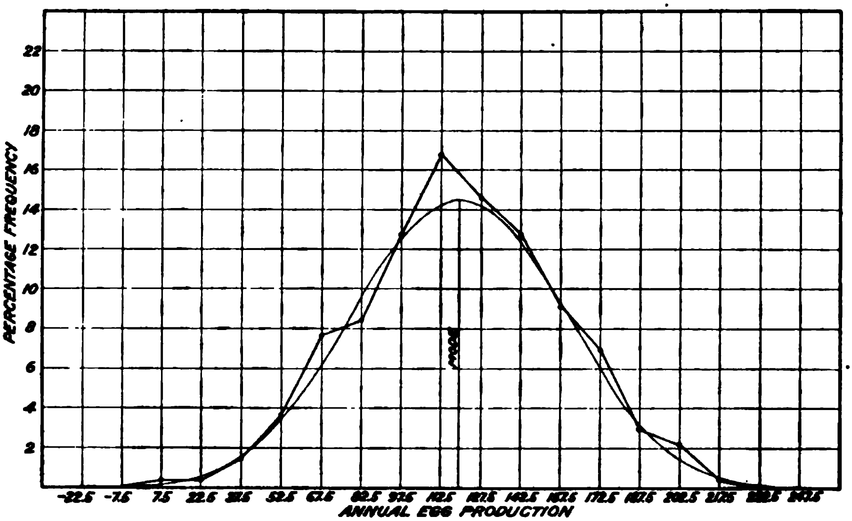

FIG. 5.—Variation in annual egg production, 1905–6, 150-bird pens.

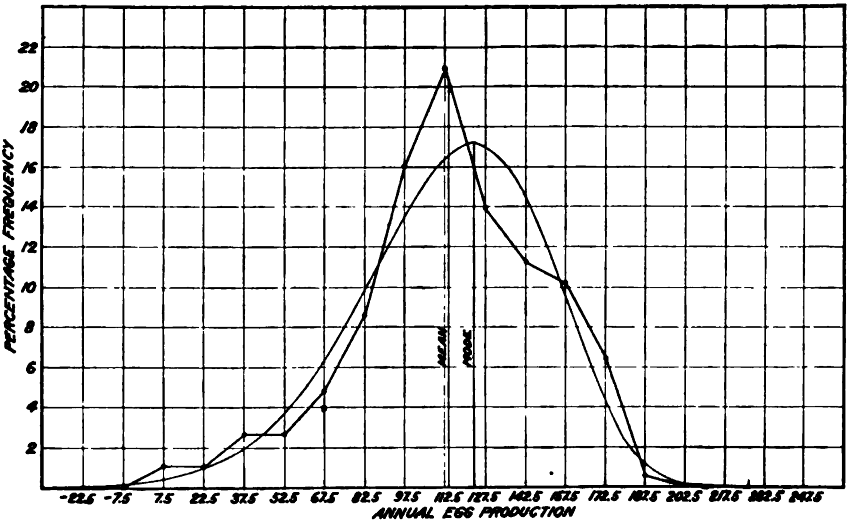

FIG. 6.—Variation in annual egg production, 1906–7, 50-bird pens.

particular curves it made no substantial difference in the range if Sheppard's corrections were or were not used. It is obvious from the diagrams that the general "fit" of all these curves is excellent. In fact, it would be difficult to get any better graduations than those given by the present curves. Curves of Type I and Type II are the only limited range curves which can possibly be used on these frequency distributions, and it is obvious from Table 4 that one of these types is not superior to the other in the matter of the estimation of the range. Hence we can not get over our difficulty by using some

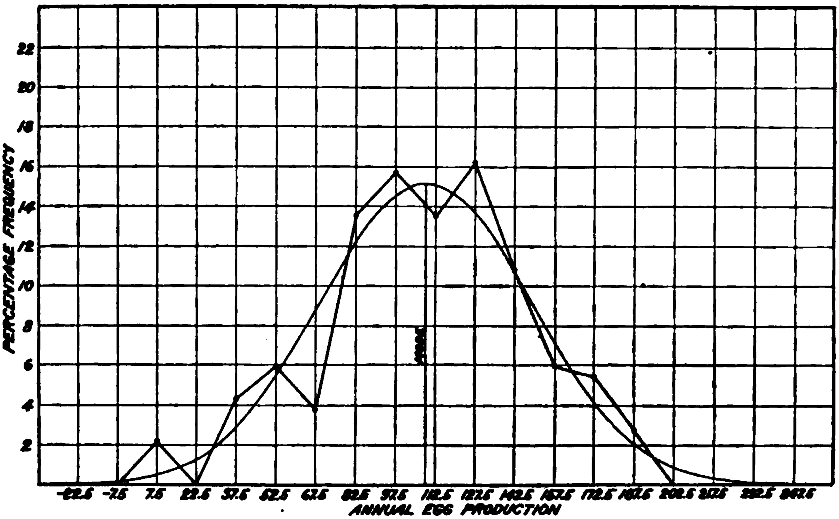

FIG. 7.—Variation in annual egg production, 1906–7, 100-bird pens.

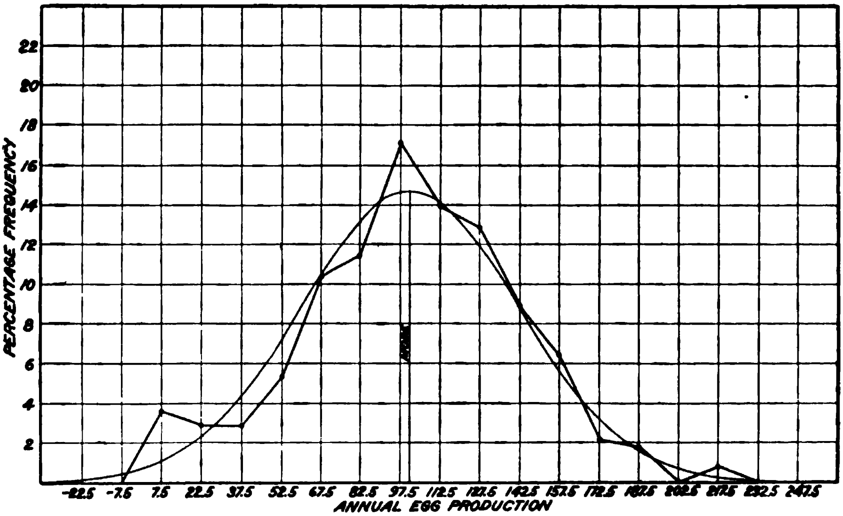

FIG. 8.—Variation in annual egg production, 1906–7, 150-bird pens.

other types of curve than those which actually have been used. A remarkable thing is that in every one of the egg-production distributions the value of the criterion κ_1 is such as to indicate that the distribution deviates from normality in the direction of a limited range curve (either Type I or II). In so far mathematical theory and biological fact agree excellently, because annual egg production is a thing which can only vary within certain limits. The remarkable thing is that while the data demand a limited range curve they lead to impossible values of the range.

Consideration of the matter leads to the conclusion that the chief reasons for the great overestimation of the range by these curves are: (*a*) That in the majority of cases the curves approach very close to the normal type. The range of the normal curve is from $-\infty$ to $+\infty$. As the limited range curve approaches the normal its range tends very rapidly to increase. (*b*) That the distributions are in every case rather irregular, owing to the relatively small number of individuals included in each. It will be observed that in each of the worst cases of extension of the range into the negative there is a group of hens laying very few eggs in the year and producing a pronounced hump in the curve near its lower end. Now the theoretical curve attempts to make allowance for this irregularity, but only does so at the expense of sending a long tail off into the negative. With a larger number of observations there is no doubt that much of the irregularity would disappear from the observational polygons, and with it would go that which in considerable measure causes the great overestimation of the range by the present curves.

The points just mentioned should be given due weight before criticism is made of the theoretical curves used because of their failure to give good estimation of the range. In addition the following facts should not be forgotten in the same connection. First, that the total frequency given by the theoretical curves beyond the observed range is in every case so small as to be practically negligible; and second, that the range is subject to a probable error, both in respect to its extent and its position. In the case of the present distributions both these probable errors must be very large for two reasons—one, that the curves approach closely the normal type; the other, that the number of individuals is statistically small.

There is some reason to believe that characters like fertility and fecundity as a rule lead to theoretical curves with considerable overestimation of the range on the negative side. This is certainly the case with our present data. It is true to an even more marked degree in Powys's[a] curves of fertility in human stock. Examination of the data and diagrams which this author gives shows that in spite of the large numbers of individuals included in his statistics and the consequent smoothness of the polygons the theoretical curves cross the zero line (no children in the family) with a frequency which is sensible in every case, and which in some cases is relatively much greater than anything we have found in the egg curves.

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[a] Loc. cit.

The general conclusion we reach is that the failure of the theoretical curves to give good estimations of the observed range is to be regarded as the result of peculiarities of the observational data rather than an inherent fault of the curves.

(4) It is of interest to note that in these curves the height of the modal ordinate y_0 when expressed as a percentage of the total frequency, is very nearly constant in all cases. Davenport[a] has recently called attention to the significance of the modal frequency as a variation constant.

CHANGES IN EGG PRODUCTION BETWEEN 1899 AND 1907.

In attempting to reach a definite conclusion regarding the obviously important matter of what has been the character and amount of change in the annual egg production during the period covered by our statistics, we are met at once by the difficulty noted earlier in this paper (p. 19). The data are not strictly comparable from year to year. Improvements were made in feeding, housing, and handling the birds during the period covered by the investigation. Proper allowance can not be made for the influence of these factors. Further, various accidents lowered the egg production in particular years. The only feasible way of getting some definite idea of how the variation constants change appears to be the following: First, to determine the changes in the actual values of the constants as they stand. These may be regarded as lower limiting values. The general trend of these having been determined, we may next proceed to modify the constants, for the influence of accidents and the like, from the actual values they show. In every case we can be sure of the general direction in which such modification should be applied. As to what its exact amount in each case should be there are, of course, no criteria. But, if we make the modification relatively large, we shall establish what may be regarded as a series of upper limiting values for the constants. We may then fairly conclude that had all conditions remained normal throughout the period covered by the data, the values exhibited by the constants would have fallen somewhere between the limits set by the actual and the modified values. While such a method can not give us precise values, it is capable of showing what the general trend of the data is. We may first examine the changes which took place in the mean or average annual egg production in the period from 1899 to 1907.

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[a] The Principles of Breeding, p. 422.

CHANGES IN MEAN EGG PRODUCTION.

In considering this problem the question immediately arises as to how the data for 1904 and subsequent years shall be treated. In these years shall we use for comparison with earlier years an average based on all the birds together (i. e., those kept in 50, 100, and 150 bird pens), or only those birds kept in flocks of one size (either 50, 100, or 150)? A little consideration leads to the conclusion that there can be but one answer to this question. We must use the records of flocks of one size only, otherwise the heterogeneity of the material will vitiate conclusions. This being the case, it is further advisable to use the data from the 50-bird flocks, since in the earlier years of the experiment the birds were kept in small flocks, with which the 50-bird flocks of later years are most nearly comparable. Consequently for the years 1904 to 1907, inclusive, we shall use the 50-bird pen records only.

The data for the changes in mean egg production are given in Table 5. The averages given here in the column headed "Actual average production" are those obtained by dividing the figures in the third column of the table by those in the second column. In other words, they are the averages from the ungrouped data given in Table I of Appendix I. On this account they differ slightly from the grouped means of Table 2.

TABLE 5.—*Changes in average egg production between 1899 and 1907.*

Year and pen.	Birds completing the year.	Eggs laid.	Actual average production.	Added to actual average.	Modified average.
1899-1900	70	9,545	136.36	0	136.36
1900-1901	85	12,192	143.44	0	143.44
1901-2	48	7,468	155.58	0	155.58
1902-3	147	19,906	135.42	[a] 23.73	159.15
1903-4	254	29,947	117.90	[b] 11.24	129.14
1904-5, 50-bird pens	283	37,943	134.07	0	134.07
1905-6, 50-bird pens	178	24,827	140.14	[b] 13.95	154.09
1906-7, 50-bird pens	187	21,175	113.24	[b] 29.53	142.77

[a] Cf. page 40.

[b] Cf. page 41.

The first point which will be noted from this table is that the averages given in the fourth column do not agree with those which have been published in the several bulletins of the Maine station, in which reports have been given of the progress of the experiment in breeding for increased egg production. Regarding this discrepancy it need only be said that the previously published averages have several times been in error from one or the other of two causes, viz, (*a*) faulty methods of handling the statistical material, and (*b*) arithmetical mistakes. Any interested person may verify for himself the averages given in Table 5, from the figures given in Table I of Appendix I, which comprises all the data which exist at the station respecting annual egg production in Barred Plymouth Rocks.

As has been pointed out earlier in the paper (p. 19), more or less serious accidents happened to lower the egg production in four out of the eight years covered in the investigation. The "actual averages" of Table 5 give the lower limit to the egg production of each year. The hens could not have produced fewer than the recorded number of eggs. In the years 1902–3, 1903–4, 1905–6, 1906–7 they probably would have produced more than the recorded number of eggs, had not the various accidents occurred. To obtain an upper limiting value for the egg production of each of these years we must add an allowance for the accident so great that it can only be regarded as unreasonably liberal. Then we can say that under entirely normal circumstances the average egg production could not have been greater than that given by the modified averages. We have then to consider separately the allowances to be added to each year's average.

In the year 1902–3 (cf. p. 16, supra) the birds are stated to have molted in December and to have laid very few eggs in that and the succeeding month. This molting was attributed to too heavy feeding during the summer and early fall months. As a matter of fact the average egg production of the 147 birds was 4.46 eggs in December, 1902, and 5.92 eggs in January, 1903; 76 birds laid in December and 77 in January—a little more than half the flock. Now, a reference to Table 2 will show that the egg production of the 50-bird pens in the year 1905–6 was the highest obtained in any year after 1901–2. Taking into account the number of birds involved it ranks highest, since in the early years there were relatively few birds. In the year 1905–6 the only point at which the laying can be regarded as abnormal is in April and May (cf. p. 18). The egg production in the other months of that year must be regarded as normal. If, then, we add to the 1902–3 average the mean egg production for the whole of the two months of December, 1905, and January, 1906, we shall have made a most liberal allowance for the accident. The mean December, 1905, (50-bird pens) production was 9.90 eggs; that for January, 1906, was 13.83 eggs. We may then add 23.73 eggs to the 1902–3 actual average, giving a modified average of 159.15 eggs. There can be no question that this figure may be taken as a safe upper limit to this year's production.

In the year 1903–4 the only disturbing factor in the records is that the birds were not moved into the houses until December 6. Hence they lack any November record, and also that for the first five days in December. The average production for the month of December was 5.67 eggs. Nevertheless, in order to establish a sufficiently high upper limit to the year's production, we may add to the actual 1903–4 average not only the normal average production for the whole month of November (1905, 50-bird pens), but also one-half of the normal average production of December (1905, 50-bird pens). This gives altogether 11.24 eggs, making the modified average for 1903–4 129.14 eggs. There is no valid reason for adding, as a modifying factor, more than the egg production of (*a*) the month during which the birds made no records and, of (*b*) one-half of the month in which they missed five days.

In the year 1905–6 all the conditions were normal, and the egg production was exceptionally high, save for a single mishap, which is said to have affected the April and May totals (cf. p. 18, supra). There is some reason for thinking that only a small allowance should be made for this mishap. The mean production for April is 16.48 eggs and that for May 11.42. In order to be sure of a sufficiently high upper limiting value, however, we may add 50 per cent of the recorded production of each of these months, making the modified April mean $16.48+8.24=24.72$, and the modified May mean $11.42+5.71=17.13$. The total modifying factor to be added to the actual mean of this year is then 13.95 eggs, making the modified mean 154.09.

In 1906–7 the application of lice killer to the roosts is stated to have caused a very serious lowering of the egg production in the months of December, 1906, and January, 1907. The actual average egg production (50-bird pens) was for the month of December 4.97 eggs and for January 5.70 eggs. Inasmuch as there is no record of the exact date when the lice killer was applied, we are compelled to add to the actual egg production of 1906–7 as a modifying factor the normal average production for the whole of the months of December and January (based, as before, on 1905 50-bird pen records). A further addition must be made to allow for the fact that this year's records are only for eleven months. There is no record for October, 1907. We may, as in the other cases, add the mean production for this month of the 1905–6 50-bird pens. This gives us the modifying term 29.53 eggs and as the modified average 142.77 eggs.

With the actual and modified averages in hand we may inquire: What has been the general trend of the mean annual egg production during the period covered by the investigation? The clearest answer to this question may be obtained by plotting the figures in the fourth and sixth columns of Table 5, and then striking through each of the two zigzag lines so obtained the best fitting straight line, as determined by the method of least squares. Such a diagram is given in figure 9.

The equations of the two straight lines are as follows:

Actual averages, $y=148.48-3.10\,x$.

Modified averages, $y=144.13+0.043\,x$.

In these equations y denotes the mean annual egg production and x the year. The origin of x is taken at 1898–99—that is, one abscissal unit to the left of the first observation. The reason for so taking the origin is obvious.

Taking the line of the actual averages, it is seen that during the first three years there is a steady rise in mean egg production. The highest mean production during the whole period of eight years is in 1901–2. From this year on the line drops, reaching a very low point in 1903–4. Rising again, the line reaches a second maximum (not so high, however, as the first) in 1905–6. The next year, 1906–7, shows the lowest average production of any year in the experiment. The general trend of the actual averages is obviously downward. This is clearly shown by the fitted line *ab*.

Turning to the line of the modified averages, we note that, while still showing the same individual year fluctuations, its general trend is almost exactly horizontal. As shown by the equation to the straight line *ac*, however, there is an extremely slight upward tendency in the modified averages. It is so small as to be entirely negligible.

Now, the truth must lie between these two lines *ab* and *ac*. One is the graduation of the lower limiting values for each year's average production, the other the graduation of the upper limiting values of what the egg production might have been had not particular accidents occurred. There appears to be but one possible conclusion. In the period from 1899 to 1907 the general trend of average annual egg production has been downward. During the period there have been, as would of course be expected, fluctuations up and down in individual years. These have been no greater, however, than might be expected as purely chance phenomena.

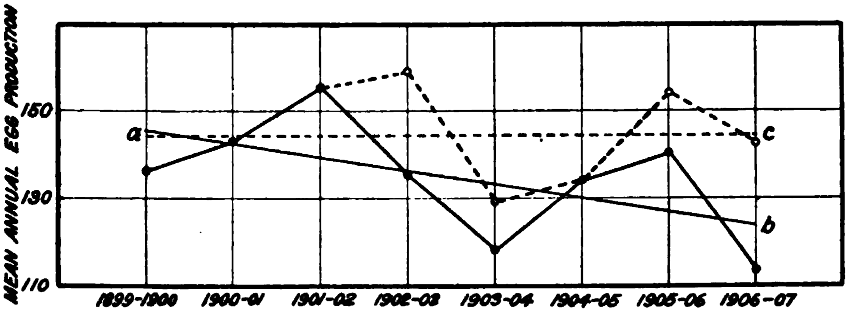

FIG. 9.—Change in mean annual egg production, 1899–1907. The solid lines show the actual averages and best-fitting straight line; the broken lines the modified averages and best-fitting straight line.

It might possibly be contended that we should reach a different conclusion if we took into consideration all the birds of the years 1904 to 1907, instead of those in 50-bird flocks. A little inspection of Table 2 shows, however, that if the mean productions of all the birds of these last three years were to be used, the general trend of the line representing the change of the mean during the whole period would be more sharply downward than it is in figure 9. This must obviously be the case, because, as the last three lines of Table 2 show, the weighted mean of the means is in each case very considerably lower than the 50-bird pen mean of the same year.

The discussion of the relation of the changes in mean annual egg production to the method of breeding practiced is deferred to a later section of the paper.

CHANGES IN THE VARIABILITY OF EGG PRODUCTION.

It has been shown that in spite of fluctuations up or down in particular years there is evidence of a gradual but steady change in mean egg production during the period covered by the breeding investigation. Is there any evidence of a similar change in the constants measuring variability in egg production? On a priori grounds we should expect to find a progressive change in variability because of the selection practiced. During the eight generations included in the investigation the immediate ancestry of the birds was strictly selected. On this account we should expect a reduction in variability until a minimum had been reached.[a] Has there been such a reduction?

In attempting to get light upon this matter one is met, as before, by the difficulty that modification ought to be made in the constants for four of the years to allow for the accidents. The matter is not quite so simple in the case of the variation-measuring constants as it is in the case of the means. The problem may be stated as follows: Let A be a character (say egg production during eleven months) having in a given population of individuals a mean value of m_1 and a standard deviation of σ_1, and let B be another character (say one month's egg production) of the same population having a mean given by m_2 and a standard deviation given by σ_2. What will be the mean and standard deviation of the sum of these two characters $A+B$ in the same population?

We have, if M be the mean and Σ the standard deviation of the combined characters,

$$M = m_1 + m_2 \dotfill \text{(i)}$$

and

$$\Sigma = \sqrt{(\sigma_1^2 + \sigma_2^2 + 2r_{12}\,\sigma_1\,\sigma_2} \dotfill \text{(ii)}$$

where r_{12} is the coefficient of correlation between A and B.

Equation (ii) presents a number of points of interest and significance. In the first place it is seen that so long at least as r_{12} is positive Σ will necessarily be greater than either σ_1 or σ_2. Now, as a matter of fact, the egg production of each single month is positively correlated with the total production for the year, as we should obviously expect it to be. That is, r_{12} is in this case always positive. Hence, if we raise the mean egg production of the year by adding as a modifying term the production of one or more months we shall at the same time increase the absolute variability in annual production as measured by the standard deviation.

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[a] For a full discussion of this matter see Pearson, K., The Law of Ancestral Inheritance. Proceedings of the Royal Society, vol. 62, pp. 386–412.

This leads to another consideration. When the total production of one group of hens is greater in a given time than that of another group in the same time it merely means that the aggregate laying within the period has been increased in one lot over what it is in the other. But, according to (ii) above, this means that at the same time the standard deviation will be greater in one lot than in the other. In other words, when the mean egg production changes we should expect the standard deviation to change in the same direction, unless some real alteration in the innate variational tendency in respect to egg production has occurred. We hence must conclude that if, as in the present case, we find the general trend of mean egg production, and at the same time that of the standard deviation in the same character to be downward, we are not justified in assuming from the standard deviation alone that there has been any progressive change in the innate variational tendency. We may expect the standard deviations to become smaller for the same reasons that the means do. The practical conclusion is that judgment of changes in variation in egg production must be based on a relative measure, such as is given by the coefficient of variation.

Further, if an increase in mean egg production means an increase in the standard deviation except there be a real change in the variational tendency of the population, then clearly it is futile to modify the standard deviations to allow for accidents, as has been done in the case of the means, because such a modification is purely artificial and represents no real change in variational tendency. Hence the coefficient of variation will be unchanged after the modification of mean and standard deviation from what it was before. To show that facts accord with theory on this point an actual case may be cited.

Table 6 gives in parallel columns the values of the chief constants of the distributions for 1904–5, when (*a*) the records of twelve months' laying (November 1, 1904, to October 31, 1905) are used, and when (*b*) the totals of the first eleven months of the same laying year (November 1, 1904, to September 30, 1905) are used.

TABLE 6.—*Egg production in 1904–5.*

Constant.*	50-bird pens.		100-bird pens.		150-bird pens.	
	(*a*) October totals.	(*b*) September totals.	(*a*) October totals.	(*b*) September totals.	(*a*) October totals.	(*b*) September totals.
Mean	134.60	129.41	133.61	127.18	114.54	107.96
Median	139.17	132.90	141.00	140.25	117.00	110.67
Mode	149.14	139.71	155.78	166.38	121.93	116.08
Standard deviation	49.49	47.25	49.41	45.90	53.04	49.56
Coefficient of variation	36.77	36.51	36.98	36.09	46.31	45.91
Skewness	−.294	−.218	−.449	−.854	−.139	−.164

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* Probable errors are not given in this table, since they are already given in Table 2 for the constants in the (*a*) columns, and those in the (*b*) columns will obviously be of substantially the same magnitude, since the number of individuals involved remains always the same.

From the table it appears that the change in standard deviations made by using twelve instead of eleven month distributions is almost exactly proportional to the change in the means. The coefficients of variation are not sensibly different in the two cases. The results then are, first, that it will not be necessary to modify the standard deviations to allow for accidents, and, second, that conclusions respecting variation in egg production must be drawn from the coefficient of variation rather than the standard deviation.

Taking the data given in Table 2, figure 10 has been prepared. It shows the change in the standard deviations during the eight years covered by the investigation. In the last three years the constants for the 50-bird pens are used as in the case of the means. The straight line is the graph of

$$y = 45.12 - 0.88\,x$$

wherein y denotes standard deviation and x number of years from 1898–99. This is the line which best fits the observations, as determined by the method of least squares.

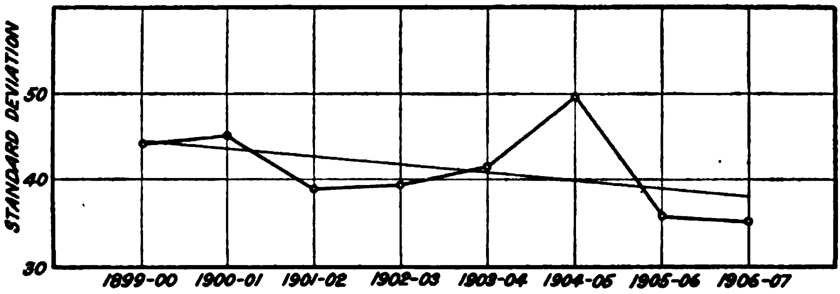

FIG. 10.—Changes in annual egg production. Standard deviations, 1899–1907.

The general trend of the observations as brought out in this diagram is obviously downward. However, since the tendency of the means was downward during the same period, it can not be concluded that there has been a real reduction in germinal variability in respect to annual egg production.

Turning to the coefficients of variation and using the data in Table 2 as before, we have the results shown in figure 11. The constants of 50-bird pens are used in the last three years.

As in the other cases, a straight line was fitted to the observations by the method of least squares. The equation to the line is in this case

$$y = 30.56 + 0.039\,x$$

where y denotes coefficient of variation and x the number of years from 1898–99.

From this diagram it is seen that the lowest relative variability was shown in the year 1901–2 and the highest in the year 1904–5.

A second minimum, nearly as low as the earlier one, occurs in 1905–6. Finally, the variability in the last year of the period (1906–7) is very nearly the same as that at the outstart eight years before. The fitted straight line is almost exactly horizontal; in fact, the change in the eight years is a little less than 0.3 of a unit. The slight slope which the line does show is upward, but no stress can be laid on so small a change on account of the values of the probable errors concerned. The general conclusion to be drawn is that during the period covered by the statistics the degree of variability in egg production in proportion to the mean has not substantially changed. There have been rather wide fluctuations during the period, but these have been as frequent and great in one direction as in the other.

CHANGES IN OTHER CONSTANTS.

Nothing in particular is to be gained by a special examination of the changes which have occurred in the median or modal egg production during the period under investigation. Both these constants run nearly parallel to the means, since the skewness is negative throughout.

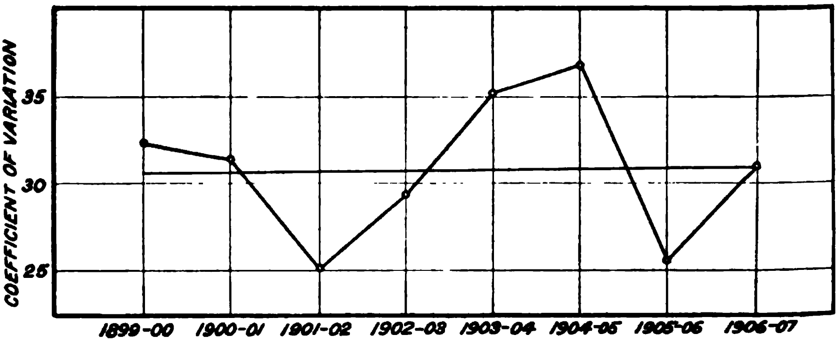

FIG. 11.—Changes in annual egg production. Coefficients of variation, 1899-1907.

It is of some interest to see the trend of the skewness. To this end figure 12 has been prepared. The data are taken from Table 2, and the 50-bird pen constants are used in the last three years. The equation to the straight line is

$$y = -0.265 - 0.0022\,x$$

where y denotes the value of the skewness and x has the same significance as in the other similar equations.

The individual year fluctuations here are rather marked, but there is no evidence of a steady progressive change in the degree or character of the asymmetry of the curves. The fitted straight line is very nearly horizontal.

Another matter of some importance is to determine the proportion of extreme variates in both directions to the total number of birds kept during the several years of the investigation. In this connection the following questions present themselves: In the period from 1899 to 1907 did the number of very exceptionally high-laying hens in proportion to the total number in the flocks increase or diminish, and how great was the change? Similarly, did the porportionate number of exceptionally poor-laying hens increase or diminish, and by what amount? One would expect, of course, in view of the selection practiced in the breeding, that in successive years there would be more "good" layers in the flock and fewer "drones." The data to answer these questions are given in Table 7. We have taken as an exceptionally high-producing hen one that laid 195 or more eggs in her first laying year, and as an exceptionally poor-laying hen one that laid less than 45 eggs in her first laying year. The fairness of these designations can hardly be questioned.

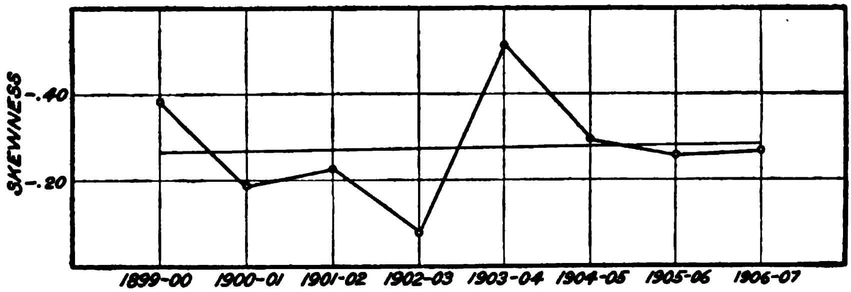

FIG. 12.—Changes in annual egg production. Skewness, 1899-1907.

Table 7 gives for each year the percentage (*a*) of birds laying less than 45 eggs and (*b*) of birds laying 195 or more eggs. In the last three years data from 50-bird pens are used.

TABLE 7.—*Percentage of the flocks laying (A) less than 45 eggs, and (B) 195 or more eggs in a year.*

Annual egg production.	1899-1900.	1900-1901.	1901-2.	1902-3.	1903-4.	50-bird pens.		
						1904-5.	1905-6.	1906-7.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Less than 45	4.29	1.18	0	1.36	6.70	7.07	0.56	4.81
195 or more	4.29	10.60	18.75	6.12	.79	12.71	5.06	0

The facts brought out in Table 7 are shown graphically in figure 13, in which the continuous lines show the change in the percentage of exceptionally high layers in the successive years and the broken lines the change in the percentage of very poor layers. The straight lines are the graphs of the following equations, deduced by the method of least squares:

$$\text{Poor layers: } y = 1.795 + 0.3225x$$
$$\text{Good layers: } y = 11.639 - 0.966x$$

In these equations y denotes percentage and x years from 1898-99.

It is noted at once from figure 13 that the changes in the proportionate numbers of exceptionally good layers in successive years very closely parallel the changes in the mean annual egg production as shown in figure 9. In 1899–1900 a little over 4 per cent of the flock laid over 195 eggs in the year. The number increased in 1900–1901 and 1901–2, reaching in this latter year the maximum point of the whole period. This maximum was a high one. Nearly 19 per cent of the flock laid 195 eggs or over. The next two years witnessed a marked decrease, the percentage of high layers reaching in 1903–4 less than 1. In 1904–5 there was another rise in the percentage, with a falling off again in 1905–6 and 1906–7. In the last year there were no birds in the 50-bird pen flocks which laid 195 eggs in the year. As is shown by the continuous straight line, instead of there having been any steady increase in the percentage of high-laying birds in these eight years there has, on the contrary, been a distinct decrease in the percentage.

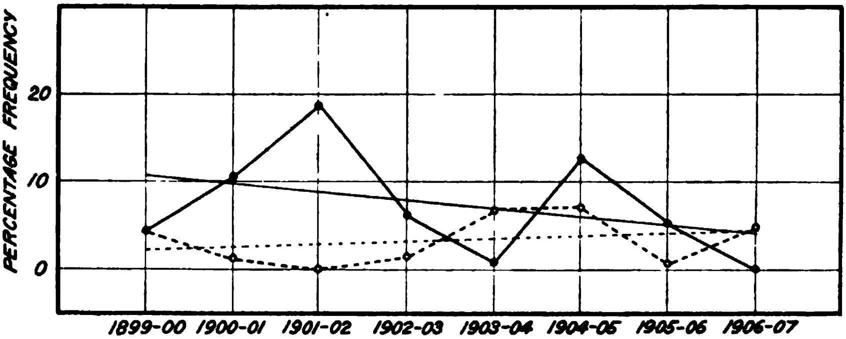

FIG. 13.—Changes in percentages of extreme variates in egg production, 1899–1907. The solid line shows the percentage of birds laying over 195 eggs; the broken line the percentage of birds laying under 45 eggs.

Turning to the poor layers, it is seen that in 1899–1900 there were exactly the same number laying less than 45 eggs as of those laying more than 195. The percentage fell to zero in 1901–2, but during the next three years steadily rose until in 1904–5, 7 per cent of the flock laid fewer than 45 eggs in the year. In 1905–6 there was a drop, with a return in the last year of nearly 5 per cent. Taking all the figures together, it is obvious that the only conclusion which can be drawn is that at the beginning of the selection experiment there were relatively few extreme "drones" in the flock; all the available evidence indicates that after eight years of selection there are as many or more such than there were at the beginning.

Further discussion of the significance of these changes in the number of extreme variates is deferred until a later section of the paper is reached.

VARIATION IN EGG PRODUCTION IN WHITE WYANDOTTES.

Up to this point we have discussed the variation in annual egg production of the Barred Plymouth Rocks only. As was pointed out in the introduction, the Maine station egg records also furnish some data on the same matter for White Wyandottes. To the discussion of these data we may next turn.

The raw material for the White Wyandottes is given in Appendix I, Table II. The grouped frequency distributions (absolute and percentage) are given in Table 8.

TABLE 8.—*Frequency distributions for variation in annual egg production of White Wyandottes.*

Eggs laid.	1899–1900.		1900–1901.		1901–2.	
	Absolute frequency.	Percentage frequency.	Absolute frequency.	Percentage frequency.	Absolute frequency.	Percentage frequency.
0 to 14	1	1.43			1	3.03
15 to 29	1	1.43				
30 to 44	1	1.43	1	1.39		
45 to 59			2	2.78	1	3.03
60 to 74	5	7.14	5	6.94		
75 to 89	5	7.14	6	8.33	2	6.06
90 to 104	6	8.57	4	5.56		
105 to 119	9	12.86	7	9.72	5	15.15
120 to 134	11	15.71	8	11.11	7	21.21
135 to 149	7	10.00	9	12.50	8	24.24
150 to 164	6	8.57	12	16.67	6	18.18
165 to 179	10	14.29	7	9.72		
180 to 194	2	2.86	4	5.56	3	9.09
195 to 209	4	5.71	4	5.56		
210 to 224	2	2.86	1	1.39		
225 to 239			2	2.78		
Total	70	100.00	72	100.01	33	99.99

It will be evident at once from Table 8 and the detailed statistics given in the Appendix that the general features of variation in egg production are very similar in White Wyandottes to what we have already found for Barred Plymouth Rocks. The range of variation is substantially the same in the two cases. As before, the number of observations is in each case too few to fill this range with anything approaching a smooth frequency distribution. It is further apparent that there is a general tendency toward negative skewness in these as in the Barred Plymouth Rock distributions.

The chief physical constants for the distributions of Table 8 are given in Table 9.

TABLE 9.—*Constants of variation in egg production, White Wyandottes.*

Laying year.	Mean.	Median.	Mode.	Standard deviation.	Coefficient of variation.	Skewness.
1899–1900	130.13±3.64	128.50±4.56	125.24	45.15±2.57	34.69±2.20	+0.108±0.097
1900–1901	135.43±3.54	139.50±4.44	147.64	44.53±2.50	32.88±2.04	− .274± .091
1901–2	130.36±4.37	137.50±5.48	151.77	37.22±3.09	28.55±2.56	− .575± .102

From Table 9 we note the following points:

1. The mean annual production of the White Wyandottes is lower in each of the three years than is that of the Barred Plymouth Rocks (Table 2) in the same year. It is extremely doubtful, however, whether this can be taken to represent a true varietal difference from which to conclude that White Wyandottes are poorer layers than Barred Plymouth Rocks. There are several reasons which make such a conclusion too doubtful to carry any weight. In the first place, the number of birds involved is too small. Further, there is no assurance that the same method of feeding is as well suited to egg production in the case of White Wyandottes as in the case of Barred Plymouth Rocks. Further, there is reason to believe that in subsequent years the descendants of the station strain of White Wyandottes came to have a mean annual egg production as high or higher than that of the station Barred Plymouth Rocks. This statement is based on a verbal communication to the writer by Prof. Gilman A. Drew, of the University of Maine, who bred these White Wyandottes after the station dropped them.

2. The White Wyandottes show substantially the same degree of individual variability in annual egg production as do the Barred Plymouth Rocks.

3. In two of the three years the distributions show negative skewness, just as in all cases with the Barred Plymouth Rocks. In the first year the skewness is positive, but its amount is so small and the number of individuals involved is so small that no particular significance is to be attached to this exception to the usual rule for curves of variation in egg production.

The conclusion, so far as any may be drawn from the limited data at hand, is that the general features of variation in annual egg production appear to be substantially the same in White Wyandottes and Barred Plymouth Rocks.

EGG PRODUCTION IN OTHER BREEDS OF FOWLS.

Reliable and extensive statistical data regarding egg production are exceedingly rare in the literature. Furthermore, whenever any such records have been published it has almost invariably been the custom not to give detailed statistics for individual birds, but rather flock averages based on larger or smaller numbers. From such material it is obviously impossible to learn anything regarding variation in egg production. While this fact is greatly to be regretted, there are certain points of interest to be gained by a comparative study of egg-production averages.

A question which will have occurred to the reader is as to how the average annual productions shown in the different years by the present statistics compare with the experience of others regarding egg production with other breeds of fowls and under different environmental conditions. Fortunately there is an abundance of data from which light may be gained on this question. For some years past there have been conducted at various places in Australia egg-laying competitions in which exact records of the number of eggs laid by pens of various breeds have been kept. The most extensive and thorough of these tests have been carried out by the Hawkesbury Agricultural College and Experimental Farm at Richmond, New South Wales. The data which that institution has accumulated on egg production are of great value. It is the fashion among poultrymen in this country to discredit these Australian egg-laying competitions and to aver that the published records of their results are wholly untrustworthy. The authors of the present paper have very carefully studied the published reports of these contests and can find no evidence that those conducted at or under the direction of agricultural colleges or government experimental farms (e. g., Hawkesbury and Rockdale competitions) at least, have not been carried out in a strictly scientific spirit and in a manner well calculated both to accumulate accurate scientific data on egg production, and, as judged by the results, to give data which are valuable from the purely practical point of view. We can see no more reason on a priori grounds for repudiating the data from these contests than one would have in repudiating any other quantitative data published by an Australian college or university.

It may be well to state briefly the manner in which these contests were carried out. The Hawkesbury competitions may be taken as types. The unit of the competition is a pen of six birds of the same breed. Intending competitors send the birds they wish to enter at a specified time to the college authorities. Each pen of six has a separate house and yard. All yards and houses are of the same size. The birds are cared for throughout the year, and the egg records are kept by an official of the college. The attempt is made to locate each house and yard in such way that the environmental conditions shall be as nearly as possible identical for all birds in the competition. One would judge from the photographs and descriptions which have been published that this ideal of environmental uniformity has been unusually well attained. At the inauguration of the first of these contests the following regulations for its conduct were drawn up:[a]

1. The competition to commence on the 1st of April and extend to the 30th of September,[b] a period of six months calendar.
2. The competitors will be bound to pen their birds during March, each pen to consist of six pullets or hens of any age, no male birds to be included.
3. All birds to be bred by the competitor.

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[a] Agricultural Gazette of New South Wales, Vol. XVIII, p. 522. 1907.

[b] The reader will not overlook the fact of the reversal of the seasons in the southern hemisphere. This first contest was a winter egg-laying competition.

4. All birds to be examined by the poultry expert on arrival at the college, and any found to be suffering from infectious or contagious disease to be rejected; in the event of a bird dying, the competitor to be allowed to replace it.
5. All eggs to become the property of the department of agriculture.
6. All competition to be decided by the greatest total number of eggs laid by each pen, eggs under 1¾ ounces not to count.
7. The market value of the eggs laid to be recorded and the weight of eggs from each pen, and prizes given for the greatest aggregate weight.
8. Records to be kept of the total quantities of the various feeds consumed and the average cost per head.

After the first contest, rule 1 was changed to include a period of one year in the test. Later rule 2 was also changed in the direction of restricting the age of competing birds, so that the year of the test was the bird's pullet year in each case.

From the standpoint of the scientific study of egg production there is one point open to serious criticism in these Australian statistics. It lies in the fact that no account is kept of the performance of individual birds. The pen instead of the individual is made the unit. This obviously detracts considerably from the scientific availability of the statistics. Another point which is somewhat open to criticism is that involved in the last clause of rule 4, which states that in event of a bird dying the owner may replace it with another. This procedure, however, probably does not seriously affect the averages for comparative purposes. The mortality is stated to have varied in the five years of competition at the Hawkesbury College between 3 and 9 per cent. Further, the plan of replacing each hen that dies with another will give averages for yearly production which we have ascertained to be very closely comparable with those of this paper which exclude the dead, i. e., which count only birds which laid during the whole year. The reason for this is apparent. Suppose a hen dies after having laid during three months. If her record is included with that of birds completing twelve months' laying, its effect will obviously be to lower the flock average. Suppose, however, that when she dies, her place is taken and the twelve months completed by another bird of the same age, and the two are counted as one bird laying twelve months. The effect on the flock average will obviously be to make it very close to what it would have been if the first bird had not died. The only difference which can be produced is that which will arise if the second bird is a distinctively better or poorer layer than the one she replaces. With a small mortality, and any care whatever in the selection of birds, the effect on flock averages must be so small as to be practically negligible. For purposes of comparison with our own statistics, in which only the birds laying the full twelve months are included, it is much better that dead birds should be replaced than not.

The following example will show how small is the effect produced on the mean production by substituting birds for those that die.

From the records for 1905–6 we first chose six birds quite at random. This was done by taking every twentieth bird, beginning with No. 23, i. e., Nos. 23, 43, 63, 83, 103, and 123. Now, let us suppose that two of these birds, say Nos. 43 and 83, died during the year of the test, and assume that No. 43 died January 31 and No. 83 July 31. Now assume that the laying year of each of these two birds was completed by another bird taken at random from the flock. How will the average of the six birds for the year, provided the substitutions are made, differ from what it would have been supposing the two birds, 43 and 83, to have completed their year for themselves? For the substituted birds two numbers were written down at random. They were Nos. 494 and 251. We have the following figures:

Bird Nos.	Actual laying of birds during whole year.	Until time of assumed death, laying of two birds assumed to have died was—	Substituted birds laid, from assumed time of death to end of year—	Assuming that substituted birds finished year for those dying the laying was—
23	152			152
43	159	Laying to Jan. 31, 33	113 (No. 494)	146
63	111			111
83	124	Laying to July 1, 116	27 (No. 251)	143
103	181			181
123	147			147
Total	874			880

Average production with no death occurring, 145.67 eggs.

Average production assuming that two birds died and that other birds completed the year for them, 146.67 eggs.

The difference between the two averages is obviously insignificant.

For purposes of comparison and illustration some of the data obtained in these Australian contests may be introduced here.

The results of the fifth and most recent Hawkesbury competition[a] which are of significance for our present inquiry are reproduced in Table 10.

TABLE 10.—*Average annual egg production of various breeds.*

[Data obtained in fifth annual egg-laying competition conducted by the Hawkesbury Agricultural College, New South Wales.]

Breed.	No. of birds.	Average egg production per hen in first laying year.	Breed.	No. of birds.	Average egg production per hen in first laying year.
Cuckoo Leghorns	6	190.16	Partridge Wyandottes	6	164.16
Langshans	18	188.88	Buff Wyandottes	12	163.75
Black Orpingtons	120	178.41	Buff Leghorns	18	160.55
S. C. Brown Leghorns	30	177.00	Buff Orpingtons	18	150.11
S. C. White Leghorns	138	174.93	White Wyandottes	24	146.70
R. C. Brown Leghorns	12	173.50	Black Leghorns	6	138.33
R. C. White Leghorns	12	172.66	Houdans	6	137.33
Golden Wyandottes	12	171.33	Faverolles	3	126.66
Silver Wyandottes	126	170.51			
Minorcas	24	168.91	Total	597	171
Rhode Island Reds	6	166.66			

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[a] Loc. cit., p. 532.

Similar data from the second Rockdale competition[a] are presented in Table 11, in which the averages given have been calculated from the raw data given in the report of the contest.

TABLE 11.—*Average annual egg production of various breeds.*

[Data obtained in second annual Rockdale egg-laying competition.]

Breed.	No. of birds.	Total eggs laid.	Average production per hen in first laying year.
Brown Leghorns	24	5,100	212.50
White Wyandottes	18	3,765	209.17
Andalusians	6	1,255	209.17
White Leghorns	96	19,763	205.86
Houdans	6	1,196	199.33
Minorcas	6	1,174	195.67
Black Orpingtons	96	18,459	192.28
Silver Wyandottes	78	14,748	189.08
R. C. Minorcas	6	1,116	186.00
Buff Orpingtons	18	3,097	172.06
Langshans	6	774	129.00
Total	360	[a]70,447	195.69

[a] This total is incorrectly given as 70,437 in the original table (loc. cit., p. 595).

From these tables it will be noted, first, that an annual egg production very considerably higher than anything observed in the experience of the Maine station is possible even with large numbers of birds. Averages of 205.86 eggs for 96 White Leghorns and 192.28 eggs for the same number of Black Orpingtons (Table 11) are far in excess of any American experience of which the authors are aware. It must, of course, always be kept in mind that these Australian averages are from selected birds, but also (in the case of figures here given) that the selection is made in advance of any direct test of the laying capacity of the selected birds. To be able to select from a flock of pullets which have not yet begun laying a pen of individuals capable of making an annual average such as those we find in these Australian statistics would certainly seem indicative of high laying capacity in the general flock. As a further illustration of this point we may cite a specific instance. In the second Rockdale competition (Table 11) the highest single pen consisted of 6 White Leghorns. In the year they laid 1,473 eggs, making an average of 245.5 eggs per bird. Now, as an examination of Table I of the appendix will show, if we select, a posteriori, the 6 best laying birds which have been found in the whole eight years covered by our statistics, we get the figures on the opposite page.

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[a] Loc. cit., pp. 591–691.

	Eggs laid.
1899–1900	237
1901–2	240
1904–5	234
1904–5	234
1904–5	248
1905–6	246
Total	1,439

These figures give an average per bird of 239.83. Or, in other words, taking the 6 best laying birds that have ever appeared in the Maine station's Barred Plymouth Rock flocks, their average annual laying is nearly six eggs lower than that of the best pen in the particular Australian competition cited. In general we must conclude that the strain of Barred Plymouth Rocks with which we are dealing can not be regarded as an exceptionally high egg-producing one in comparison with other strains and breeds.

A question which constantly recurs to the mind of one studying the problem of egg production is: How does the egg production of the "improved" strains and breeds of the present day compare with that of the domesticated fowl of earlier times?

It is the common opinion that, with the greater attention which has been paid in recent years to poultry raising as a definite and independent branch of agriculture, there has been a great improvement in the so-called "utility" points of the domestic fowl. There have unquestionably been great improvements made in the last twenty-five years in the management of poultry. Equally there can be no doubt that with this improvement in methods of management there has been a decided betterment in the general average condition, in respect to "utility" points, of the domestic fowl. It is not so clear, however, whether within modern times there has been any marked amelioration in the innate qualities on which high egg production depends. This may at first sight appear to be an unwarranted statement. A study of the available evidence, however, we believe, can only lead to the position of doubt on the question just expressed

It should be understood clearly that the question is not as to whether, for example, the average egg production, within a given period, of hens in general is at the present time greater than it was fifty or a hundred years ago. It undoubtedly is. Rather, the significant point is whether, if a given lot of hens of, say a century ago, had been fed, housed, and handled in the same way that our so-called best laying strains are to-day, their egg production would not have been substantially the same as that of the present-day flock. The answer to this question, so far as egg production is concerned, is by no means certain.[a]

The difficulty, of course, lies in getting adequate and trustworthy evidence as to the egg-producing ability of fowls in any but the most recent times. In the older literature one finds plenty of statements that such and such a breed is "noted for its excellence in laying," and the like, but any precise statement as to the criterion of "excellence in laying" then in vogue is almost invariably wanting. Further, when numerical data are given they demand the most careful scrutiny before they can be accepted, because too often it appears from the context that the recorder has some personal interest in making the egg-production record a high one. In such cases the data must obviously be taken with a grain of salt. We have been able, however, to find a few definite records of egg production in earlier times, which appear to be in every respect trustworthy. There is no more reason to doubt their accuracy than there is to doubt the accuracy of any quantitative data of the same period. A few such records may be cited.

In the Journal of Agriculture (English), Volume XI, pages 339 and 340, the following detailed records of egg production are given, on the authority of the editor, in an article on artificial hatching:

Produce of three Poland pullets hatched in the preceding June, from December 1, 1835, to December 1, 1836.

	Eggs laid.		Eggs laid.
December	12	July	55
January	50	August	55
February	48	September	55
March	50	October	25
April	54	November	9
May	55		
June	56	Total	524

These figures give as an average production for the year 174.67 eggs per bird, certainly a very creditable performance. We can discover no reason for doubting the accuracy of these figures. They are not presented as in any way exceptional, but rather so far as can be judged from the context, as a definite numerical statement, by way of illustration, of what any poultry raiser might reasonably expect the performance of his hens to be under ordinarily favorable conditions.

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[a] It is of course certain if the inquiry concerns itself with the so-called "show" points of poultry, such as "shape," "feather," color, and the like. In respect to these characters fanciers have wonderfully improved all the standard breeds. A glance at the plates in such works as Tegetmeier's Poultry Book, for example, affords sufficient evidence of the improvement here.

Another statement of the same general tenor is to be found in an "Essay on the rearing and management of poultry" by William Trotter, published in the Journal of the Royal Agricultural Society in 1851 (vol. 12, pp. 161–202). The essay was awarded a prize by the Royal Agricultural Society in the year mentioned, and hence, we may feel reasonably sure, was subjected to careful and critical scrutiny before publication. It seems, under the circumstances, altogether unlikely that any serious misstatement of fact would have occurred in the essay in the first instance, or if it had occurred, would have been allowed to pass into print. On page 169 (loc. cit.) the following statement is to be found: "Hens of the best laying varieties will lay in a season from 160 to 270 eggs each, averaging 215." If any credence whatever is to be put in this statement, it would appear to indicate that as high egg production as any that we know now was regarded as at least possible fifty years ago.

In another essay which was awarded a prize by the Royal Agricultural Society, and was published in the journal of that society in the year 1867 (series 2, vol. 3, pp. 520–532) a still more definite and precise statement respecting egg production is to be found. The essay is by Mrs. F. Somerville, and its title is "On the rearing and management of poultry on an ordinary farm." The same conclusions as were reached concerning Mr. Trotter's essay appear to apply regarding the trustworthiness of statements in this latter one. On page 532 (loc. cit.) it is stated that in one year "104 hens produced 13,739 eggs *exclusive of those set.*[a] This leads to an average production per hen of 132.11 eggs in the year. The author goes on to state that the 104 hens "reared 372 chickens, besides hatching the ducks and guinea fowls." Now, assuming that it took but 400 eggs to produce 372 chickens, we have the total egg production 14,139 in the year. This gives an average of just under 136 eggs. This can only be regarded as comparing very favorably indeed with the best of our modern records of egg production in equally large flocks, especially when it is considered that these hens had to do all the incubating of at least 372 hen eggs, 79 duck eggs, and 42 guinea-fowl eggs, these being the numbers of each hatched.

We have a number of other references to statements similar to those quoted, but what have been given will suffice for our present purpose. They show that there is trustworthy evidence that at about the middle and the first half of the last century there existed individual birds and flocks of poultry whose ability as egg producers was at least the equal of that to be found in poultry at the present time.

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[a] Our italics.

THE INFLUENCE OF CERTAIN HOUSING CONDITIONS ON ANNUAL EGG PRODUCTION.

As has been noted earlier in this paper (p. 17), there has been conducted during the last three years covered by our statistics an experiment to determine the influence of size of flock and amount of floor space per bird on egg production. The general plan of this experiment has already been described and need be only briefly reviewed here. The birds in the experiment were handled in flocks of 50, 100, and 150. The pens were so constructed that in the flocks of 50 and 100 birds there was an allotment of 4.8 square feet of floor space, while in the flocks of 150 birds there was an allotment of 3.2 square feet of floor space per bird. The general plan of construction of the houses in which these birds were kept throughout the course of the experiment has been fully described in earlier publications[a] and need not be taken up again here. The data accumulated in this experiment furnish evidence on two different questions. In the first place, we have data on the influence of the number of birds associated together in one pen on the egg production when the floor space per bird is the same. Evidence of this sort one can, of course, get by comparing the egg records for 50-bird pens and 100-bird pens. In addition there are data on the further question of the influence of amount of floor space per se on the egg production when one brings into the comparison the 150-bird pens.

In conducting this experiment on the influence of floor space on egg production great care has been exercised to make constant all conditions other than housing. The birds used in the experiment have all been of substantially similar breeding. They have been in every case birds bred from mothers laying between 160 and 199 eggs in a year and from fathers whose mothers and earlier ancestors in the female line were birds laying 200 or more eggs in their first laying year. Furthermore, in sorting the birds into the various pens in the fall of each year great care has been taken to make a pro rata distribution of the pullets of different qualities in the different pens. Thus, for example, the pullets on the range would be examined and the very best of them selected, then this selected group would be apportioned in the proper proportion to the different pens in the experiment. The 100-bird pens would receive twice as many of this class of birds as did the 50-bird pens and the 150-bird pens three times as many. Then the second choice would be made of the pullets on the range, and these again divided among the houses in the same proportional manner. This procedure assured as even distribution of birds in the several components of the experiment as probably could in any way be obtained.

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[a] Maine Agricultural Experiment Station Bulletin 100 and Bureau of Animal Industry Bulletin 90.

It is the purpose at this point to discuss the results of this floor-space experiment only in so far as they have to do with the influence of this factor on annual egg production. In later parts of the work we shall discuss the results of the experiment in respect to the laying in different months of the year, and in other ways shall attempt to make a closer analysis of the data.

We may examine first the influence of the factors size of flock and amount of floor space per bird on the mean or average annual egg production. The data on this matter are presented in Table 12. In addition to the actual means of the different pens for each year there is also given in the last column of this table the excess in the number of eggs produced per bird in the 50-bird pens over that in the 150-bird pens. It will be noted that in this table the actual means are given. It is, for obvious reasons, not necessary to make any modification of any of these averages to allow for the effect of accidents, as was done earlier in the paper in discussing the change in average annual production from year to year. Here the figures which we desire to compare are all based on records of the same year; hence there is every reason to suppose that the influence of any accident which may have occurred will be equally distributed in all parts of the data. That is to say, for example, there is no evidence for supposing that either of the accidents which occurred in the years 1905–6 and 1906–7 affected the 50-bird pens in a different way from what they did either the 100 or the 150 bird pens. Consequently we are justified in using the actual means as they stand.

TABLE 12. *Relation of size of flock and floor space to mean annual egg production.*

Year.	Mean annual egg production.			Excess of 50 over 150 bird pens.
	50-bird pens.	100-bird pens.	150-bird pens.	
1904–5	134.60±1.98	133.61±3.47	114.54±3.02	20.06±3.61
1905–6	140.31±1.81	127.50±2.03	119.43±1.54	20.88±2.38
1906–7	114.16±1.74	108.53±1.92	101.08±1.64	13.08±2.39
Mean	129.69	123.21	111.68	18.01

The data in Table 12 are shown graphically in figure 14. From the table and the diagram we note at once the following points:

1. It is obvious that the mean annual egg production is very markedly affected by differences in the environmental factors with which we are dealing. In each year there is a decided difference in the average production of the different pens. Further, it is clear that the general trend of the annual averages is downward as the number of birds in the pen increases. In every instance the mean for the 100-bird pens is smaller than that for the 50-bird pens of the same year, and the mean for the 150-bird pens is again smaller in every case than is that for the 100-bird pens.

2. The decrease in the mean annual production as we pass from the 50-bird pens to the 100-bird pens is, in round numbers, taking the average figures for the whole three years, about 6 eggs. The difference between these two types of pens is not altogether regular from year to year. In the year 1904–5 it is so small as to be insignificant in comparison with its probable error. In 1905–6 the difference is relatively large, amounting to approximately a dozen eggs. In 1906–7 it is about the average, namely, 6 eggs. These results, it will be observed, are perfectly consistent in their general trend throughout the whole course of the experiment, and there appears to be but one conclusion possible. That conclusion is that with the general plan of feeding and housing followed at the Maine station, even though the amount of floor space per individual bird remains the same, the average egg production per bird in a year's laying is distinctly and significantly smaller when the birds are in flocks of 100 than it is when they are in flocks of 50 birds each.

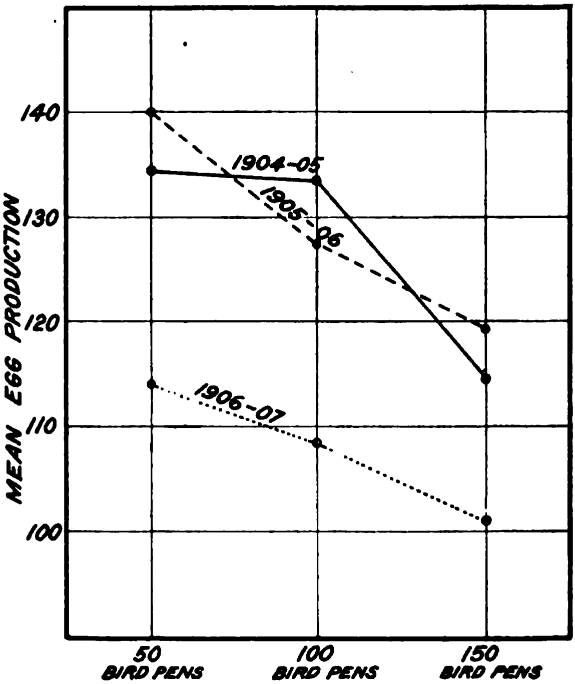

FIG. 14.—Mean annual egg production with different amounts of floor space per bird.

3. The differences between the averages for 100-bird pens and 150-bird pens are, on the whole, distinctly larger than those between the 50-bird and the 100-bird pens. Taking average figures, the mean annual production is approximately a dozen eggs smaller in the 150-bird pens than it is in the 100-bird pens. As before, the absolute amount of the decrease varies in different years, although the general trend is entirely consistent throughout the course of the experiment.

From these results it must be concluded that under the conditions of the experiment, when we have the combined influence of an increase of number of birds in the flock together with a decrease in the amount of floor space per bird, there is a notable decrease in the average annual egg production.

4. If we consider the maximum difference due to the influence of different amounts of floor space and flock size, as shown between 50 and 150 bird pens, it is seen to be large in amount and relatively constant in different years. In round numbers, the birds in the 50-bird pens averaged to lay a dozen and a half eggs more per bird than did those in the 150-bird pens. Such a large difference is of special interest, as showing what a considerable effect on egg production the environmental factors with which we are dealing may have.

We may next turn to a consideration of the influence of size of flock and floor space per bird on the variability in annual egg production. An examination of Table 2 shows that as the number of birds per pen increases, the standard deviation in egg production also tends to increase. This indicates at once that there is a real increase in the variability of egg production of the large as compared with the small flocks because, as has just been pointed out, the mean egg production decreases as the size of the flock increases. In order to obtain a fair notion of the change in relative variability, we may, as before, resort to the coefficient of variability as the measure. In Table 13 are given the coefficients of variation for each of the different sized flocks and for each of the three years over which the experiment extended. In Table 13, as in Table 12, there is also given in the last column a statement of the maximum differences shown in the pens of different sizes.

TABLE 13.—*Relation of size of flock and floor space to variation in annual egg production.*

Year.	Coefficient of variation in egg production.			Excess of 150 over 50-bird pens.
	50-bird pens.	100-bird pens.	150-bird pens.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1904–5	36.77±1.17	36.98±2.07	46.31±2.23	9.54±2.52
1905–6	25.48±0.97	31.84±1.23	31.72±1.00	6.24±1.39
1906–7	30.91±1.18	35.54±1.39	40.43±1.32	9.52±1.77
Mean	31.05	34.45	39.49	8.43

The data of Table 13 are shown graphically in figure 15. From the table and the diagram we note the following points:

1. The relative variability in annual egg production is evidently influenced very decidedly by the environmental conditions. The general trend of the variability, as has been pointed out, is to increase as the size of the flock increases, although there is not so great a degree of regularity in this change as there is in the case of mean egg production.

2. As to the amount of change in variability with the increase in the size of the flock, if we take average figures, it would appear that it is fairly uniform from 50 to 100 and from 100 to 150 bird pens. In each case there is an increase on the average of about 4 per cent in the coefficient of variation. In individual years the increase may not be uniform. For example, in 1904–5 there is practically no difference in the variability in the 50 and 100 bird pens. Again, in 1905–6 the 100-bird pens and the 150-bird pens show substantially the same degree of variation. This apparent equality in variability in egg production in different pens is probably to be explained, however, merely as a result of random sampling, the real tendency being that indicated in the average figures already discussed.

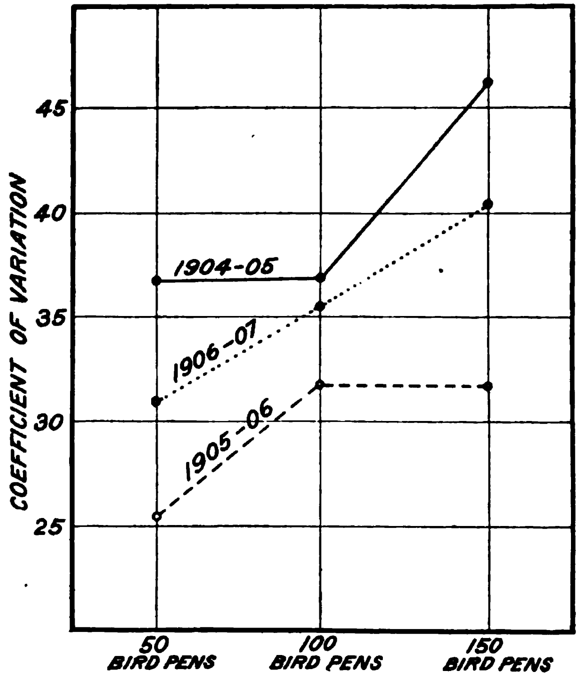

FIG. 15.—Variability in annual egg production with different amounts of floor space per bird.

3. Taking the maximum differences in variability produced by the environmental differences, we see that they are in the neighborhood of 8 to 10 per cent. Since the probable errors of these differences are about 2 per cent, it is obvious that the effect on variation in annual egg production of the environmental factors, with which we are dealing, is an entirely real and definite one. The general result, from present data, would appear to be that an environmental influence which tends to lower the mean annual egg production also tends to increase the variability of the egg production, so that poor-producing flocks are, at the same time, very variable in egg production.

Putting all the results of the floor-space experiment together, they lead to the conclusion that as the size of the flock is increased there tends to be a decrease in the average annual egg production per bird, and this relation holds true whether the floor space per bird is or is not diminished. Further, those conditions relative to size of flock and floor space which tend to cause lower mean annual egg production also tend to increase variation in the production of the flock as a whole. It must be borne in mind that these conclusions apply only to annual egg production, and that from them one must not draw the practical conclusion that it is desirable under all conditions to keep laying hens in small flocks. It will be shown in Part II of this paper, when we come to examine the influence of size of flock and floor space on the egg production during different seasons of the year, that the practical conclusion, relative to the proper floor space and size of flock for laying birds, will be somewhat modified from what one would conclude from the data here presented. For this reason we shall defer drawing any practical conclusions from this experiment or making any suggestions relative to flock management in regard to floor space until the data to be brought out in Part II are at hand.

It will no doubt have occurred to the reader that the results set forth in this section regarding the effect of a strictly environmental factor on egg production have a very significant bearing on the results of the breeding experiment which has been conducted with these birds. It has been shown that a comparatively slight environmental change can in one year produce relatively great changes in mean annual egg production, and, still more important, in the variability of egg production. From this fact alone it would seem doubtful if the method of breeding which has been followed has made any real change whatever in the innate characteristics of the strain relative to egg production. A full discussion of this point will, however, be deferred until a later section of the paper, where the whole question of the influence of selection on egg production will be taken up.

EGG PRODUCTION IN THE SECOND LAYING YEAR.

Up to this point we have dealt entirely with the egg production in the first laying year, all the egg records ending with the second October following the hatching of the birds. In an earlier section of the paper it has been shown that this first-year egg production may be taken as a fair measure of the innate egg-producing capacity of a bird. It is, however, a matter of some interest to study egg production during the later portion of a hen's life. Unfortunately the data available for such a study are exceedingly meager. In the records of the Maine station there are returns of more than one year's laying for less than a hundred birds. Furthermore, these records of the laying during more than one year are not all that could be desired in another respect. They are records of selected birds and not of a random sample of any particular flock. The birds chosen to be carried through more than one year and subjected to trap-nest records are in most instances birds which laid unusually well during their first laying year. As a matter of fact, as will appear later, the mean egg production of these birds in their first laying year was higher than any other average production which has ever been observed at this station. This, of course, is merely the result of selecting especially high-laying birds. The available data on egg production in the first two laying years have already been published.[a] From these published data have been taken only the birds which are recorded as having laid some eggs, at least, in both of the first two laying years. This has given for the present discussion the records of the egg laying for two years of 66 birds. The egg records for the two years of these birds are given in Table III of Appendix I.

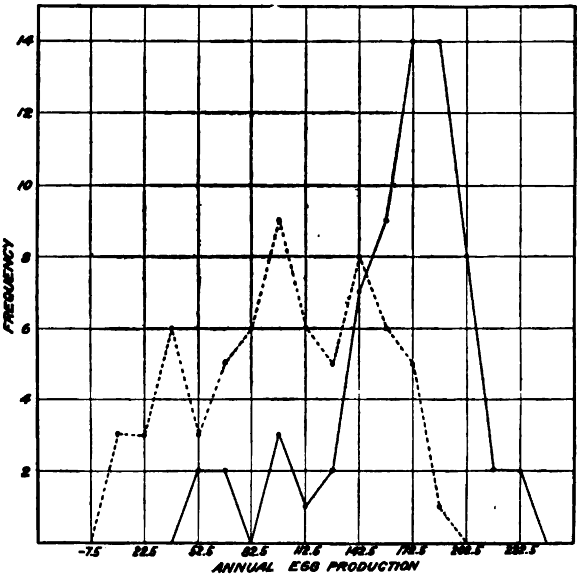

FIG. 16.—Frequency polygons for egg production during the first and second years of laying. The solid line gives the record of the first year, the broken line those of the second year.

By grouping the egg production as in the other cases into class units of 15 eggs each and forming separate frequency distributions for the first and second years' laying, we have the results shown graphically in figure 16.

The number of individuals involved is so small that the variation polygons are rather irregular. However, they suffice to show the general trend of the variation in these two periods. It is noted at once that the variation polygon for the first year's laying possesses the same general characteristics as the others which have been discussed earlier in the paper. Further, as is of course to be expected, the diagram shows that the second year's production is on the average very decidedly smaller than that of the first year. The material shows in the first year an observational range of variation of 190 eggs—the lowest-yielding bird of the lot having laid 47 eggs during the year and the highest 237 eggs. In the second laying year of the same individuals the lowest-yielding bird laid only 8 eggs during the year and the highest-yielding bird 185 eggs, giving a total observed range of 177 eggs.

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[a] Maine Agricultural Experiment Station Bulletin 93, p. 75. 1903.

While the polygons are much too irregular, on account of the relative fewness of the individuals involved, to enable any final conclusion to be drawn regarding such matters as skewness, yet it seems to be indicated that the polygon of variation for the second year's laying is much more symmetrical about the mean than is that for the first year's laying. The first year polygon is clearly negatively skew, like the great majority of the other egg-production frequency distributions which we have examined.

Turning to the constants of variation in egg production for the two years, we have the results set forth in Table 14.

TABLE 14.—*Constants of variation in first and second year egg production.*

Year.	Mean.	Standard deviation.	Coefficient of variation.
First laying year	162.95±3.30	39.71±2.33	24.37±1.50
Second laying year	100.47±3.99	48.06±2.82	47.84±3.38

The first point to be noted from Table 14 is the relatively high mean production for the first year—in round numbers, 163 eggs. As has been pointed out, this is due merely to the fact that it is based on a group of birds selected for their egg production and not on a random sample of any year's flock. In the second year, in this particular case, the mean production decreased by rather more than a third of what it was in the first year. Whether the difference between the laying of the first and second years would be the same in a random sample of birds it is impossible now to say. We hope later to get some definite evidence on this point.

It is obvious from the table that, however it is measured, the second year's egg production is very much more variable than is that of the first year. The standard deviation for the second year's production is nearly 10 eggs greater than is that for the first year's. Since at the same time the mean egg production has decreased, it is obvious that the relative variability, as measured by the coefficient of variation, must be very much greater in the second year. This is in fact the case. The relative variability in the second year is nearly twice as great as it is in the first. It will be noted that the variability of this group of 66 birds, in spite of the fact that they were a selected lot, is not widely different from what we have found for samples not especially selected.

A point of much interest is to determine what degree of correlation exists between the laying of the first and the second years. If a bird is an especially good layer in its pullet year will it, on the average, be an especially good layer in its second laying year; or, conversely, if it is a very poor layer in the pullet year will it, in the average case, be an exceptionally poor layer in its second year of life? The only way in which a definite answer can be obtained to this question is to measure the degree of correlation which actually exists between the first and the second year's laying, and then see whether the coefficient of correlation so obtained is significant in comparison with its probable error. Accordingly, we have calculated this coefficient for our present material. On account of the relatively small number of birds represented in the statistics we have not grouped the material in any way in making the calculation. For this material the correlation between the first and the second year's egg production is given by a coefficient,

$$r = 0.032 \pm 0.083$$

while this correlation is positive, yet it is extremely small and obviously insignificant in comparison with its probable error. We can only conclude that so far as any evidence from our present material is concerned there is no sensible correlation between the egg production of the first laying year and that of the second.

We may next consider the characteristics of variation in the combined egg production of the first and second laying years. This is a point of practical as well as theoretical interest, because it has been contended that the proper measure of a bird's producing capacity is the laying of the first two years rather than that of the first year. At the present time there are being conducted in Australia egg-laying competitions in which the egg production of the first two years is taken as the unit. If we add together for each of our 66 birds the production in the first and the second year and then form a frequency distribution, using a class unit of 40 eggs, we get the distribution given in Table 15. In addition to the frequency distribution itself, there are also included in Table 15 the values of the chief physical constants deduced from the distribution.

Table 15.—*Distribution and constants of variation in combined first two years' egg production.*

Eggs laid.	Frequency.	Eggs laid.	Frequency.
80–119	3	360–399	4
120–159	3		
160–199	5	Total	66
200–239	12		
240–279	15	Mean	263.42±5.84
280–319	12	Standard deviation	70.29±4.13
320–359	12	Coefficient of variation	26.68±1.67

It is obvious that the general characteristics of variation in the egg production of the first two years combined are very similar, so far as may be judged from the present material, to what has been found for the production of the first year alone. The frequency distribution is apparently unimodal and negatively skew. The comparatively low mean egg production given by the two-year distribution is obviously to be explained by the fact just brought out that there is no sensible correlation between the egg production of the two years. Obviously, if the bird which was a relatively high producer in its first laying year was also always or usually a relatively high producer in the second laying year we should get a higher mean egg production in the same lot of birds than that which we have here. With the increase in the mean egg production over that of a single year is found, as would be expected, an increase in the standard deviation. This increase, however, is almost precisely proportional to that which occurs in the mean; hence we are compelled to conclude that the relative variability in respect to the first two years' egg production is not substantially different (as is indicated by the coefficient of variation) from that of the first year alone.

So far as may be judged from such meager data as we now have, there seems no particular reason for regularly taking as a unit in egg-production investigations or contests two years' laying instead of one year's. The important characteristics of variation appear not to be essentially different for the longer unit from what they are for the shorter. Such a conclusion can for the present, however, be only provisional.

It is much to be regretted that more extensive material on this matter of egg production in years subsequent to the pullet year is not at hand. What we have attempted to do in this section is to discuss the very meager material which now exists. It is a part of the plans for future poultry work at the Maine station to make further study of this point, and we hope that later we may be able to present a fuller and more adequate discussion of the matter.

SELECTION AND EGG PRODUCTION.

We may now turn to the consideration of the results of the breeding experiment which gave origin to the statistics on which this paper is based, so far as these results concern the annual egg production. An account of the experiment has been given earlier in this paper (pp. 11, 12). Its underlying idea was to improve the egg-laying quality of a particular strain of hens by breeding only from the best producers and their sons. It should be said that until the last year of the experiment (1906–7) practically no records were ever kept by which it could be told what birds were the parents of any particular individual offspring. It was simply known that only eggs of high-producing hens were incubated and that the males that fertilized these eggs were sons of high-producing mothers. In a very few cases records were kept of the mothers of individual birds, and in still fewer cases of the fathers. These facts will make it plain why it is necessary to discuss the results of this breeding experiment in the manner which will be followed in this section. The lack of the most fundamental data of all in any breeding investigation—namely, the pedigree data—makes it impossible to attack the problem of the influence of selection on egg production in the usual straightforward fashion. Obviously, the proper way to study the matter would be to form correlation tables between parent and offspring in regard to egg production and then evaluate the degree of intensity of inheritance of this character, compare the variability in successive generations following selection, etc. It is impossible to proceed in this way, since we have only mass data instead of individual data. The only conclusions which can be reached must be such as can be deduced from mass data.

We may first consider the question of the degree of intensity of the selection which has been practiced. In the several accounts of the breeding experiment [a] it is stated that only birds which laid 160 or more eggs in their pullet year were ever used as breeders. Now, while at first thought this may seem like an entirely uniform procedure, a little consideration shows that it is far from being such, so far as intensity of selection is concerned. All selection must be of or about a type. This is equally true whether the one making the selection has a definite and fixed type in mind and picks out individuals as nearly like it as possible, or, as in the present case, the selection is made by truncating the general population distribution and taking as the selected individuals all those falling in the portion cut off. One thinks of selection as most intense when the selected individuals conform closest to type. The most intense selection possible would be to take out of a population only those individuals which exactly conform to the type within the limit of the unit of measurement. Thus, in the present material, suppose it to be agreed that the type to which selection was to be made was an egg production of 180 eggs in the year. Then we should get the most intense selection possible by taking as breeders only birds laying exactly 180 eggs. As birds having productions differing from 180 eggs were taken, we should be selecting with less and less stringency.

These considerations indicate at once a method whereby one may measure with precision the intensity or stringency of the selection applied in any particular case. From what has been said it is apparent that the smaller the variation exhibited by the selected stock in comparison with that exhibited by the general population from which the selection is made, by so much is the selection more intense or stringent. Hence, if one takes the ratio of the standard deviation of the selected stock to the standard deviation of the general population, the result will be a coefficient measuring intensity of selection. If we use for this coefficient the letter S we have

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[a] See particularly Bureau of Animal Industry Bulletin 90.

$$S=\frac{\sigma_M}{\sigma_P}$$

wherein σ_M denotes the standard deviation of the selected stock and σ_P that of the general population. Now obviously the limits of this coefficient S are 0 and $+1$. When the selection is as stringent as possible and each selected individual is exactly like the type (within the limits of the unit of measurement), there will be no variation in the selected stock, and hence σ_M will equal zero, and consequently S will also. If on the other hand the selected individuals are chosen at random, they will approach no more closely to the type than do the individuals of the general population. In that case we shall have $\sigma_M=\sigma_P$ and $S=1$. Between these two limits, 0 and 1, S will vary in magnitude inversely as the intensity of the selection. We may for convenience call S the coefficient of selection.

In the breeding experiment on which we are here reporting, only hens laying more than 160 eggs in their pullet year were used for breeding. Of such hens, so far as we are able to learn, practically all were used. There were a few rejections because of small or badly colored eggs, but the number of such birds was very small. As has been pointed out above (p. 67), it is now impossible to tell exactly what birds were used as breeders in earlier years. Consequently, we can not give absolute figures for the intensity of selection. What can be done, however, is to determine the intensity of selection in each year of the experiment, assuming that all birds laying 160 or more eggs in their pullet year were used as breeders. The results so obtained, while not absolutely correct, will come very close to the true facts. For all practical purposes one may consider the figures to give the actual intensity of the selection practiced. In Table 16 it is assumed that all birds laying over 160 eggs in the pullet year were mothers of the flock of the second year following their hatching.

TABLE 16.—*Intensity of selection practiced in the breeding, 1899–1907.*

Year.	General population mean.	Mother's mean.	Difference in means.	General population standard deviation.	Mother's standard deviation.	Difference in standard deviations.	Intensity of selection.	Percentage of mothers to general population.
1899–1900	136.36	179.83	43.47	44.03	20.59	23.44	0.468	34.28
1900–1901	143.44	184.83	41.39	45.02	16.06	28.96	.357	42.36
1901–2	155.58	188.20	32.62	38.94	20.56	18.38	.528	47.92
1902–3	136.48	182.62	46.14	39.34	17.86	21.48	.454	27.88
1903–4	117.87	172.70	54.83	41.43	10.86	30.57	.262	15.76
1904–5 [a]	129.07	186.87	57.80	51.30	18.78	32.52	.366	30.10
1905–6 [a]	128.44	174.09	45.65	39.07	13.86	25.21	.355	20.94
1906–7 [a]	106.99	172.33	65.34	39.09	10.84	28.25	.277	8.88

[a] For these years, just as in the earlier ones, all the birds in the flock are taken together in determining the constants in this table. In selecting breeding stock no account was made of the size of the pens from which they came. Hence we have no reason to treat 50, 100, and 150 bird pens separately.

From Table 16 we note the following points:

1. The difference between the mean of the selected stock (mothers' mean) and that of the general population varies rather widely in different years. It is, for obvious reasons, least when the general population mean is highest, and greatest when the general population mean is lowest. This difference ranges in value from about 33 eggs in 1901–2 to 65 eggs in 1906–7, and averages 48.41.

2. Similarly there is considerable fluctuation from year to year in the differences between the standard deviation of selected stock and the general population. These differences range between 18 and 32 eggs, with an average of 26.10.

3. The intensity of selection, as measured by the coefficient, is rather great throughout the whole experiment. In the years when the selection is most stringent the coefficient only drops to a value of about one-fourth, while in the year of least intense selection the value is more than one-half. These figures mean that never in the course of the experiment was the selection more than three-fourths as stringent as it was theoretically possible to make it, and it was usually decidedly less close than that.

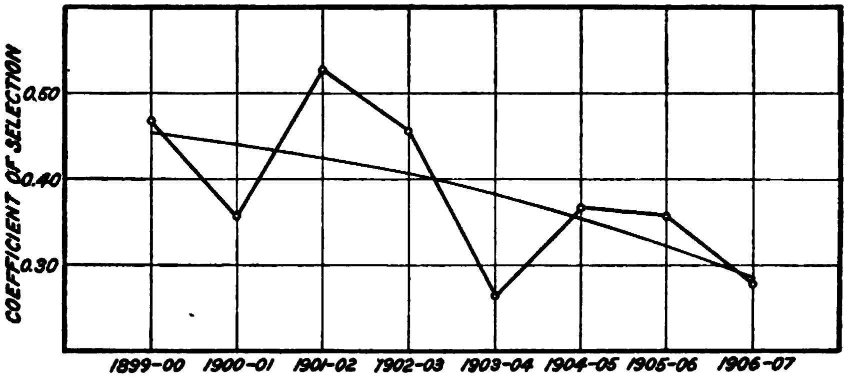

FIG. 17.—Change in intensity of selection, 1899-1907.

4. The general trend of selection during the period was to become relatively more stringent; that is, the value of the coefficient of selection diminished during the experiment. This is clearly shown in figure 17. In this figure the zigzag line shows the fluctuation in the value of the coefficient in the different years. The smooth line is the parabola

$$y = 0.4620 - 0.0062x - 0.0020x^2$$

the constants of which were determined by the method of least squares.

The reason for the decrease in the value of the coefficient of selection is clearly to be found in the fact that there was a steady decrease in the egg production of the flocks during the experiment, as has been shown above (p. 42). As the laying becomes poorer there will be fewer and fewer of the flock producing over 160 eggs. Consequently the variation exhibited in the selected stock will steadily become smaller both absolutely and in proportion to that of the general population (coefficient of selection).

5. The last column of the table shows for each year the proportion of the flock which produced over 160 eggs. As we should expect from what has gone before, this proportion diminishes in the later years of the experiment.

Having examined the method and degree of selection practiced, we may next consider the results. According to current theories regarding the inheritance of fluctuating variations, the following are the primary and fundamental results which one would expect to get in such an experiment as this:

1. A gradual and steady tendency for the mean annual egg production to increase with each successive generation. Since all the ancestry for at least eight generations was selected, it would be expected that at the end of this period there would be a marked gain in egg production over what existed at the beginning.

2. A small but not the less distinct and definite decrease in the variability of egg production during the course of the experiment.

3. A considerable degree of fixity of the improvement gained, such that ordinary environmental fluctuations would not in a single generation cause all that had been presumably gained by selection to be lost.

Now, it has been shown in this paper that, so far as annual egg production is concerned, the actual results obtained in this breeding experiment are as follows:

1. The only change which occurred in the mean egg production, aside from individual year fluctuations, was a small but entirely definite decrease during the eight years (pp. 39–42). Further the percentage of exceptionally high producers in the flocks has somewhat decreased during the course of the experiment, and at the same time the proportion of extremely poor producers has slightly increased (p. 48).

2. The variation in annual egg production has remained unchanged throughout the course of the experiment except for minor fluctuations in individual years (p. 46).

3. There is no evidence that the quality of high egg productiveness is any more fixed in the strain at the end of the experiment than it was at the beginning. During the last three years of the experiment it has been definitely shown that a relatively small environmental change is able to produce a very large difference in the mean egg production in flocks of hens of exactly the same selected ancestry (pp. 58–63). Such a result could not occur if the character had been fixed by the selective breeding.

These results we believe to be of great interest and importance, alike from the standpoint of evolution theory and that of practical poultry husbandry. While in a sense they mark a failure to attain that for which the work was undertaken—namely, an improvement of egg laying by this particular method of breeding—yet they possess much educational value. We have here an extensive selection experiment carried out in the traditional time-honored fashion, but with records of a character which make it possible to appreciate the net results with certainty. These results are not in accord with current theoretical ideas, but they are in remarkable accord with the experience of Nilsson at the Svalöf experiment station in breeding cereals, as recently described by De Vries.[a] This is sufficiently shown by the following quotation. Speaking of the earlier experience of the Svalöf station in breeding cereals by the ordinary method of continued selection, De Vries says (loc. cit., pp. 62 and 63):

> The deficiencies of the method could not escape observation. All those which were of purely technical nature could be overcome, and on this side of the problem a high degree of perfection was attained. But there were other weak points which were related to the very foundation principles of the method. Among these, the principal one was that the continuous selection of the best specimens in an arbitrary direction did not lead to improvement in all cases. Quite on the contrary, success was rare; so rare, even, that it could almost be looked upon as an exception. The fact itself was not new, since in Germany, also, only in exceptional cases a real improvement had been obtained. But, of course, usually only successful instances are published, and concerning the remainder ordinarily no evidence is at hand.
>
> In Svalöf, however, where numerous experiments of the same kind, but with different varieties of cereals, were conducted side by side, the fact could not escape observation. Soon the idea suggested itself that if success is an exception, the principle involved in the method can hardly be a valuable one, at least, not one on which the breeder may confidently rely.

The fact that in the present case of long-continued selection for a particular kind of animal production we get results so exactly paralleling those obtained in plant breeding when the same method of selection is practiced is certainly an interesting one. A strong argument of those who have endeavored to controvert the views of De Vries regarding the significance of fluctuating and mutational variation in the creation or amelioration of varieties has been the history of domesticated animals. Is the idea that all improvement of breeds on the animal side has been brought about by the continued selection of small "fluctuating" variations as well grounded as it is commonly supposed to be?

It appears to us to be idle to attempt any explanation at present as to why this breeding experiment resulted as it did. Of the objective results we are certain, and we have endeavored to set them forth clearly and distinctly. But for the interpretation of them we need much additional data which we do not as yet possess. Such data we hope in course of time to accumulate. Beginning with the breeding season of 1908 we shall have an exact individual pedigree record of every individual bird in the station's poultry.plant. These records must ultimately throw light on the meaning of our present selection results.

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[a] De Vries, H., Plant Breeding, pp. xiii and 360. Chicago, 1907.

The practical conclusion to be drawn from the results of this breeding experiment seems to us to be clear. It is that the improvement of a strain of hens in egg-producing ability by selective breeding is not so simple a matter as it has been supposed to be. . Nothing could be simpler than breeding from high producers to get high producers. But if this method of breeding totally fails to get high producers—in other words, if the daughters prove not to be like the mothers in egg production—it can not fail to excite wonder as to whether the simplicity of the method is not its chief (possibly its only) recommendation. Anyone who makes a thorough first-hand study of an extensive selection experiment carried out, as was this one, by the so-called German method without testing the transmitting power of individual organisms, can not fail to be impressed, we believe, with the fact that the improvement of a race by selective breeding is a vastly more complicated matter than it is assumed to be by those who maintain that one need only to breed from the best to insure improvement. The supposed "facts" of heredity on which the practical stock breeder (working for utility points) operates are in very large part inferences rather than facts. What is needed more than anything else for the advancement of the stock-breeding industry in all its phases is an accumulation of definite knowledge of the fundamental principles of the hereditary process. All breeding operations must be based on the laws of inheritance in organisms. The practical stock breeder is able to work out the applications of these laws for himself. What he most needs is broader and deeper knowledge of the laws themselves. This knowledge must come from thoroughgoing purely scientific investigations.

SUMMARY OF RESULTS AND CONCLUSIONS.

This paper constitutes Part I of a general study of egg production in the domestic fowl. It deals with variation in annual egg production. For the purposes of this investigation "annual egg production" is taken to be the total laying in a year beginning with November 1. For the most part the present paper is concerned with the egg production of the pullet year. The data on which the work is based are the trap-nest records kept since 1898 at the Maine Agricultural Experiment Station in connection with an experiment in breeding by selection for high egg production.

The chief results of this part of the investigation are summarily stated in the following paragraphs. Unless something directly to the contrary is said, all the statements in this summary have to do with the egg production in a single variety, namely, the Barred Plymouth Rock.

1. Variation in annual egg production exhibits the following characteristics: (*a*) The observed range of variation is from zero to about 250 eggs; (*b*) the distributions are usually unimodal and unsymmetrical. The asymmetry or skewness, when it exists, is always in the negative direction; that is, the modal egg production is always larger than the mean egg production. (*c*) The amount of variation in egg production is both absolutely and relatively large. The mean value of the coefficient of variation from all our data is about 34 per cent. (*d*) Variation in egg production, so far as our statistics show, belongs to the type of continuous, so-called "fluctuating" variation.

2. Analytically considered, such of the variation polygons as are skew are found to conform to Pearson's Type I curve. The symmetrical distributions belong either to his Type II or the normal curve of errors. The range of variation is in nearly all cases greatly overestimated by the theoretical curves. It is pointed out that this appears to be a characteristic of fecundity curves frequently.

3. It is shown that during the period covered by the statistics (1899–1907), which covers practically the whole period of the breeding experiment, there has been, apart from fluctuations up and down in individual years, a small but steady decrease in the mean or average annual egg production.

4. During the same period (1899–1907) the variability in annual egg production has not sensibly changed. There have been chance fluctuations up and down in individual years, but there has been no steady trend toward lower or higher variability. The same statement applies to the skewness of the distributions in the period covered by the investigation.

5. The percentage of extremely high layers (producing more than 195 eggs in the pullet year) in the flock decreased during the period from 1899 to 1907. The percentage of exceptionally poor layers (producing less than 45 eggs in the pullet year) in the flock increased during the same period.

6. The general characteristics of variation in annual egg production in White Wyandottes are essentially similar to those described above for variation in Barred Plymouth Rocks.

7. Evidence from the literature is presented tending to show (*a*) that it is possible to get average annual egg yields higher than any of those which have been observed at the Maine Experiment Station, and (*b*) that records exist showing that in exceptional cases average annual egg yields were obtained during the middle and earlier half of last century, which were just as high as any we now know.

8. When the laying hens were kept in flocks of 100 birds each the average annual egg production per bird was distinctly and significantly lower than when they were kept in flocks of 50 birds each, though the number of square feet of floor space per bird was the same in the two cases and all other environmental conditions were made as nearly as possible identical.

9. Laying birds kept in flocks of 150 birds each, and with somewhat less floor space per bird than those kept in flocks of 50 and 100 birds each, have in every case an average annual egg production significantly smaller than that of the birds kept in smaller flocks. It is pointed out that great caution must be shown in drawing practical conclusions from these results relative to housing because we are here dealing only with annual egg production.

10. Those conditions of housing and flock size which tend to lower the mean annual egg production are found to tend to increase the variability of the production, so that poor producing flocks are at the same time flocks very variable in production, and vice versa.

11. Egg production in the second laying year is found, on the basis of rather meager data, to average about a third lower and to be distinctly more variable than that in the pullet year. There is no sensible correlation between the production of the first and second year.

12. During the period covered by the statistics all birds used for breeding have been the offspring of mothers laying 160 or more eggs in their pullet year and of fathers which were the sons of high-producing mothers. It is now possible to determine what have been the results of this extensive experiment in selection. It is shown that the intensity or stringency of selection became relatively greater during the progress of the experiment, though the absolute standard of selection remained the same. It is further shown that there is no evidence that the selective breeding practiced has improved the strain in respect to egg production. On the contrary, the data show that (*a*) the mean egg production has diminished during the experiment, (*b*) the variability in egg production has remained unchanged, and (*c*) in the last years of the experiment relatively slight environmental changes caused very marked changes in the flock productiveness. This is obviously inconsistent with the view that any particular type of egg production has in any way been fixed in the strain by the breeding.

APPENDIX I.

In the following three tables are given the detailed raw data on which the present paper is based:

TABLE I.—*Egg production of Barred Plymouth Rocks.*

Eggs produced in pullet year.	Number of birds producing in each year the specified number of eggs.													
	1899-1900.	1900-1901.	1901-2	902-31	1903-4	1904-5 50-bird pens.	1904-5 100-bird pens.	1904-5 150-bird pens.	1905-6 50-bird pens.	1905-6 100-bird pens.	1905-6 150-bird pens.	1906-7 50-bird pens.	1906-7 100-bird pens.	1906-7 150-bird pens.
1					1	1		1						1
2					2	1		1						
3								2					1	4
4								2						2
5					2									
6												1	1	1
7					1			1				1		
9														2
10													1	
11					1						1		1	
14						1				1				
15								1		1				
17										1		1		
18								1						
19							1							1
20						1								1
21								1						1
22							1			1	1			
23		1			2			1						
24														1
25				1	1	1						1		
26								1						1
27								1						
28					1									2
29				1	1	1								1
30						2	1					1		
31										1	1		1	
32	1					1						1		
33													1	1
34						1								
35														1
36	1				1	2					1			
37						1								1
38						1					1			
39					1	2	2					2	1	1
40						2	1	1	1	1			1	1
41					1									2
42	1				1	1							1	
43					1					1		1	1	
44						1		2			1		2	1
45							1	2					1	1
46						1		2				1	1	1
47		1			1						1		1	
48					1	1					1			2
49						2		2					1	
50					1							1	1	2
51		1			1	1			1		1	1	1	
52				1					1	2		1		
53						1					1	1		
54		1			1	1		1			1			
55	1				1			2					1	2
56		1			2						3			2
57					2									1
58											1		3	
59	1									1	1		1	4
60				1		2	1	1			1	1		
61	1	1									1			3
62					1					1	1	1		2
63					1				1	1	1			1

TABLE I.—*Egg production of Barred Plymouth Rocks*—Continued.

Eggs produced in pullet year.	Number of birds producing in each year the specified number of eggs.													
	1899–1900.	1900–1901.	1901–2	1902–3	1903–4	1904–5 50-bird pens.	1904–5 100-bird pens.	1904–5 150-bird pens.	1905–6 50-bird pens.	1905–6 100-bird pens.	1905–6 150-bird pens.	1906–7 50-bird pens.	1906–7 100-bird pens.	1906–7 150-bird pens.
64					1	2		1		3	3	2		2
65						1							1	2
66										1	2	1		1
67											3			1
68	2				2	1					1		1	5
69				1	1		1		1	1	1			2
70	1	1	1	2				1	1		2		1	2
71					1		1	1				2	1	1
72		1				2		1	1	1	1		2	1
73				1	2	1					2	1	1	4
74		1			1			1			2	1		2
75								2	1	1	3	1	2	1
76	1	1			1	1	1	2	1			1	2	2
77					1	1		2			3	1	2	1
78						1		1	1	2		2	2	1
79									1	1		2	3	
80	1			1	1	2	2	1	1				3	3
81				1	1	3		2			4	1	1	3
82				2	2	1		2			3		2	3
83				1	6	1		1		2		3	1	5
84					1	1	1			3	1	1		2
85					1							1		1
86				2	1	1	1	2	1	1	2	1	4	2
87		1				1	1		1	4	2		1	4
88	1				1				1		2	1	1	3
89	1		1	1	4	2	2		1		3	1	1	1
90	1			1	1	2					3	2		1
91		1		2	1		1		1			1	4	3
92		1		2		2	2	2		2	2	6	3	2
93			1				1	2			5	1	2	3
94		1		2	3		1	1	1	1	3		1	4
95		1		1				3		1	2	1	1	4
96				1	1	1			1	1	2	3	1	3
97					1	2	1		1	1	3	3	3	4
98	1				5	2	1				2	2	3	4
99		1	1	1	1		2	1	1	2	3	2	1	2
100	1	1		2	2	1			1	1	1	2		4
101				1	2	1			2	2	1	1	2	3
102				2	2	1	1		1	2	4	2	1	3
103					1	1		1	2	2	2	2	2	3
104	1			2	4	3			2	2	2	2	5	5
105		1	2	2	1	2	1	1	1	4	4			1
106				1	1	2			2	1	1	4	2	4
107		1		6	5	2	2			3	4	4	3	1
108				2	3	3		1	2	2	1			1
109					3	4		1	1	3	2	4	2	3
110		2		1	4	1	1	2	3	1	2	2	2	
111			2	1	.2	3	2	2	1	1	7	1	2	4
112					3	4	1	1	3		9	4	2	2
113			1	1		2			2		1	1	2	2
114				2		1		1	3	1	4	3	2	1
115	1	2		1	3	3		1		3	3	1	1	6
116			2			3		4	2	3	2	2	2	5
117	1	1			2	2	1	3	2		2	5	2	3
118			1		1	3	2	1	1	3	2	2	2	4
119				1	1	4	1		2	1	2	6	1	2
120	1			1	1	2		1	1		1	4	3	2
121				1	1	2		1	2	1	1	2	1	3
122			1		5	2	1			1	3	1		2
123		1		3	2			1	4	3	6		2	4
124			1		2			1	7	1	3	2	6	3
125	1			1	5	1			3	1	2	4	2	2
126			2	3	3	3				2	3	1		4
127				1	2	2	1	1		5	1	2		1
128	1				1		2	2		1	2	2	2	1
129	2	2		1	8	2	1	1	1	3	2	1	2	2
130				2	1	1			1		2	3	2	
131	1	1		1	6	4		1	1	2	1	2	4	1
132	1	2		1	5	3		1		1	6	1	2	
133	1			2	3	2			2	2	1	1	2	9
134	2				7			2	2	2	6		2	2
135	1			1	3			2	2	6	2	2	4	2
136		1		4	4	2	1		1	3	3	2	3	4
137	1	4		1	3	5		1	1	3	5	1		
138	1	1		3	3	4		1	1	2	6			1
139	1	2		1	2	3			1			2	2	3

TABLE I.—*Egg production of Barred Plymouth Rocks*—Continued.

Eggs produced in pullet year.	Number of birds producing in each year the specified number of eggs.													
	1899–1900.	1900–1901.	1901–2	1902–3	1903–4	1904–5 50-bird pens.	1904–5 100-bird pens.	1904–5 150-bird pens.	1905–6 50-bird pens.	1905–6 100-bird pens.	1905–6 150-bird pens.	1906–7 50-bird pens.	1906–7 100-bird pens.	1906–7 150-bird pens.
140				4		4	1		2	1	2	1	1	1
141	2	1		1	4	3				2	2	3	2	1
142				1	3	2		2	1		2	2	1	4
143	1			1	2	1		2	1	1	1		2	2
144	1	1		2	3	1		1	2	2	1	1		2
145	1	2		2	1	1			2	3	2	3	1	1
146		2		1	3	2	2	1	2		3		1	
147	1			1	1	4	2		3		2	4	1	
148			1	2	3	4	1				2		1	1
149	1	1		1	2	4			3		2		1	3
150	1					5		3	2	2	1	1	2	3
151				1	3		1	1	1	1	1	2		
152	1			1	3	4			4	3	4	1	1	
153	2		2	2	4	1			3		4	3	1	1
154		1		1	1	2	2	2	2	1	1	1	1	1
155		2	3	2			1	1	3	5	1	1	1	
156				1	1	3	2	1	2	3	2	1		2
157		1	1	3	2	3		3	2	1	2			3
158	1		1	1		4	1		4	1	2	2	1	1
159	1		1		1	2		1	2	1	2	1		
160		1		1			1	2	1	4	1			4
161				1	1	2		2	2	2	1		1	2
162			1		5	5	1		1					
163	3		1	2	3	1	1	2	1	3	1	1	1	
164			1	1	5	1	1	1	2		2	5	2	1
165		1		3	1	2	1		1		2	1		2
166	1	1		2	3	6		2	2	2	2	1		1
167	1	2		2	1	1	1	1	3	1	3	2		1
168			2	1	1	3	1	1			1		4	1
169	1	1		1		1	1		3	1				
170	2	3	1	1		2	1	3	3	1		1	1	1
171	1			2	2			1	1	1		1		
172				1	1	3	3	1	1	1	3	1		
173			2			1				2	1	1		
174	1	1	1		1	2	1		1	1	2	2	2	
175	2	1	1	1	1						1	1	1	
176	1			1	3	5		1	1	3	1			
177		2		1	1			1	1	1	3		1	
178	1	1		1	1	1	1					1		
179	1	1	1	1		1	1			2			1	
180	1			2	1		1	1	2	1	1			2
181	2	2				1		1	2	2				2
182		1		1	2	1	1				2			
183	1	1			1	1		2			2		1	
184					1	2	1		1		1		1	
185	1	2		3		3	1		3	1				
186					1	1	1	1	2	1		1	1	
187					1		1		1					
188			1						3	2				
189		1	1	1	1	1			2		1			
190		3		1		3			3	1			1	1
191		1		1			1			1				
192		1				1	1		1		1		1	
193	1		1			2				1				
194								1		2				
195		1						1	2	1	1			
196		1	1		1				1		2			
197						1	1		2	1				
198			1								1			
199		1					1	1	1					
200		2		1		4								
201			1			5	2	1		1				
202						2	1				1			
203						1	3	1	2					
204						2		2						
205			1	1		4								
206			1			3								
207						1								
208	1					2			1		1			
209		2			1		1							
210				1		2								1
211	1		1			2								1
212						1	1	1						
213		1	1											
214											1			

TABLE I.—*Egg production of Barred Plymouth Rocks*—Continued.

Eggs produced in pullet year.	Number of birds producing in each year the specified number of eggs.													
	1899-1900.	1900-1901.	1901-2	1902-3	1903-4	1904-5 50-bird pens.	1904-5 100-bird pens.	1904-5 150-bird pens.	1905-6 50-bird pens.	1905-6 100-bird pens.	1905-6 150-bird pens.	1906-7 50-bird pens.	1906-7 100-bird pens.	1906-7 150-bird pens.
215					1									
217				1		1								
220				2				1						
221				1		1								
222			1	1										
225				1										
226						1								
234		1				2								
237	1													
240			1											
246										1				
248						1								
Total	70	85	48	147	254	283	92	140	178	182	275	187	185	281

TABLE II.—*Egg production of White Wyandottes.*

Eggs produced in pullet year.	Number of birds producing in each year the specified number of eggs.			Eggs produced in pullet year.	Number of birds producing in each year the specified number of eggs.			Eggs produced in pullet year.	Number of birds producing in each year the specified number of eggs.		
	1899-1900.	1900-1	1901-2		1899-1900	1900-1	1901-2		1899-1900	1900-1	1901-2
1			1	115	1			160			2
10	1			117	1			161		3	1
22	1			118	1	1		162			1
36		1		119	1	3	1	163	1	2	
41	1			120	2		2	164	1		
52		1		121		1		165		1	
54		1		124		2		166	1	2	
55			1	125	1			167	1	1	
60		1		126	2			171	2		
61	1			127	1			173	1	2	
62	1	1		128	2	2	3	175	1		
64		1		129	1		1	176		1	
65		1		130	1		1	178	2		
66	1			131		1		179	2		
68	2			132	1	1		180	1		
72		1		134		1		181		1	
78	2	1	1	136	1	1		183		1	
80		1		137			1	184			1
81		1		138		1		185			1
82			1	139		1	1	186		2	
83	1			140		1	2	191			1
86		1		141	1	1		193	1		
87	2	2		142	2	1		195	1	1	
90		2		143			2	196	1		
93	1			144	1	2		203		1	
98	1			146		1		207		1	
99	1	1		147	1			208	1	1	
100	1			149	1		2	209	1		
103		1		150		1		214	1		
104	2			152			1	217	1	1	
107	2	1	1	153	1	1		226		1	
108	2	1	1	154		1		233		1	
109			1	155	1						
110			1	156	2	1	1	Total	70	72	33
113	1	1		159		3					

TABLE III.—*Egg production of the same individual hens in the first and second laying years.*

Eggs laid in—		Eggs laid in—		Eggs laid in—		Eggs laid in—	
First year.	Second year.	First year.	Second year.	First year.	Second year.	First year.	Second year.
161	61	135	161	195	166	190	88
175	8	137	168	200	176	170	103
155	118	165	165	185	147	189	13
165	112	151	82	209	138	95	82
175	94	154	94	234	150	177	58
181	159	120	115	191	73	175	98
142	89	143	46	99	67	157	86
191	94	129	125	183	124	167	51
165	151	191	147	107	22	200	185
169	40	151	150	61	20	209	102
140	103	138	148	213	137	170	107
160	145	208	127	185	106	51	86
201	30	237	102	92	35	181	70
136	130	163	71	190	143	47	44
184	99	211	145	169	30	192	133
152	162	196	16	74	12		
155	116	170	172	182	34		

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U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 110, PART II.

A. D. MELVIN, CHIEF OF BUREAU.

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A BIOMETRICAL STUDY OF EGG PRODUCTION IN THE DOMESTIC FOWL.

II. SEASONAL DISTRIBUTION OF EGG PRODUCTION.

BY

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1911.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., March 10, 1910.

Sir: I have the honor to transmit herewith a manuscript entitled "A Biometrical Study of Egg Production in the Domestic Fowl. II. Seasonal Distribution of Egg Production," by Drs. Raymond Pearl and Frank M. Surface. Part I of this work, dealing with the variation in annual egg production, was published last year as Bulletin 110, Part I, of this Bureau. I respectfully recommend that the present paper be published as Part II of that bulletin.

Respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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A BIOMETRICAL STUDY OF EGG PRODUCTION IN THE DOMESTIC FOWL.

II. SEASONAL DISTRIBUTION OF EGG PRODUCTION.[a]

INTRODUCTION.

In Part I of this study[b] the subject dealt with was variation in total annual egg production. This phase of egg production formed the logical starting point for a general investigation of the subject, and furnished an outline or programme of the underlying problems which must be solved in such a general investigation. Annual egg-production records furnish final mass results. There are involved in the attainment of these total annual results a large number of individual factors. The ultimate purpose of the study of egg production must be to separate and analyze each one of these factors individually so that it may be possible to control in greater or less degree total annual egg production through an intimate knowledge of the individual factors on which it depends.

In starting the analytical investigation of the problems outlined by the study of total annual production, the first question which presents itself is as to how egg production is, in general, distributed throughout the year. It is, of course, a perfectly well-known fact that on the average a flock of hens will not have just one-twelfth of their total yearly production in each month of the year. Certain seasons of the year have been recognized from the beginning of the domestication of poultry as primarily egg-producing seasons, whereas in certain other seasons it has always been particularly difficult to get eggs.

The whole matter of the seasonal distribution of egg production is extremely important from a practical as well as from a theoretical standpoint. The differences in the seasonal distribution of egg production cause corresponding differences in the price of eggs. In that season of the year when the poultryman finds it hardest to get eggs he is able to get the highest prices for such as he can send to market.

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[a] Papers from the Biological Laboratory of the Maine Agricultural Experiment Station, No. 20.

[b] A Biometrical Study of Egg Production in the Domestic Fowl. I. Variation in Annual Egg Production. U. S. Department of Agriculture, Bureau of Animal Industry, Bulletin 110, pp. 1–80. 1909.

The practical importance of a study of the seasonal distribution of egg production is well brought out if one compares in regard to this matter hens whose total annual production is the same. Such a comparison for a few individuals has been made in a recent paper by the present writers.[a] It is there shown that the money return is not by any means the same for all "200-egg" hens. A "200-egg" hen may bring in less money in a year than a bird laying very considerably fewer eggs, but producing them at a time when prices are high. The aim of the practical poultryman is to increase as much as possible his winter egg production. The matter of learning how to increase winter egg production is one of the primary problems which is under investigation at the present time in connection with the poultry work at the Maine Experiment Station.

From the theoretical side the investigation of the seasonal distribution of egg production is of the highest importance. Egg production is a part of the reproductive process in birds, and in the wild progenitors of domestic poultry it was only great enough for the perpetuation of the race. Around this primary, inherent egg-producing ability all the improvement in egg production shown by modern breeds of fowls has been built. In attempting to learn the underlying principles which have made this improvement possible lies the only hope that we may be able to continue the improvement in the future. It is important to know with as great exactness and detail as possible how the added egg production of modern races relates quantitatively and seasonally to the egg production of the wild representatives of the genus *Gallus*.

It is the purpose of this part of the paper to analyze the total annual egg-production records of the Maine station in respect to the seasonal distribution of production. In this analysis the month will be taken as the unit of discussion. The reason for taking the month as the unit is not primarily a theoretical but a practical one. It is obvious enough that a division of the year into calendar months is an arbitrary one from the standpoint of the biology of egg production. There is, for example, no natural or inherent reason for including an egg laid on Tuesday, February 1, with a different group from that in which an egg laid on Monday, January 31, is placed. The practical reason which makes it necessary to use the month as the first unit for the finer analysis of the total annual production is that, previous to the laying year, beginning November 1, 1907, there are, in the egg-production records of the station, no data available for smaller units of grouping than calendar months. From that date to the present time a daily egg record for each individual hen has been preserved. In the older records of the station the month is the smallest unit of which account was kept in the permanent records.

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[a] Poultry Notes—1908. Maine Agricultural Experiment Station, Bulletin 165, pp. 29–48. 1909.

While at first thought there may seem to be serious theoretical objections to the use of the month as a unit in the study of egg production, because of its somewhat arbitrary and unnatural character, yet a little consideration will show that any fixed unit of egg production whatsoever, except the day, is an arbitrary and in some degree unnatural one. Calendar months are not more open to criticism in this regard than are any other time units. In spite of the fact that the month is a more or less arbitrary division of the year from the standpoint of the biology of the hen, it yet remains that much of importance may be learned regarding the seasonal distribution of egg production by the analytical study of monthly records, and this unit is on the whole probably more satisfactory for the purpose than any other fixed time unit which could in actual practice be taken. The truly natural seasonal divisions of the year in respect to egg production are, we believe, considerably larger than the month. Evidence in our possession, a part of which will be presented in this paper, has led to this conclusion. At the present time the egg records of the station are being discussed on the basis of the division of the year into these larger seasonal periods.[a] Before this could be done, however, it was necessary to know the facts regarding the monthly distribution. To make any adequate analytical study of the subject of seasonal distribution a unit is necessary which is, on the one hand, longer than the day (otherwise the true seasonal changes will be obscured by the minor fluctuations of daily records) and on the other hand shorter than the natural seasonal divisions of the year. The month as a unit stands between these extremes.

With the month as a unit for a discussion of the seasonal distribution of egg production, a whole series of problems suggest themselves, as, for instance: What is the mean or average production for each month of the year with large flocks of birds when uniform methods of feeding and management are followed throughout the year? What is the exact form of the mean monthly egg production curve for the year? What is the comparative variability in respect to egg production in the different months of the year? Is the variability greatest in those months where the mean production is highest, or vice versa? Or is there no relation between mean production and variability in production? In general, what is the form of a monthly egg production variability curve for the year? These questions again suggest others. Is the seasonal distribution curve of egg production of the same character in different years; and Is the seasonal curve of variability in egg production of the same type in different years? How nearly alike are these curves for different breeds of fowls and under different climatic conditions or methods of management?

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[a] Cf., for example, Maine Experiment Station, Bulletins 165 and 166, 1909.

In the previous part of this study an account was given of the experiment carried on at the Maine station for nine years to ascertain the effect of selection on average annual egg production. It was shown in that paper that the general trend of the average annual egg production had been downward throughout this time, although a rigid selection of high-producing parents had been maintained during the period. In the present part of the investigation we have to consider what was the effect of this method of breeding, so far as the monthly distribution of egg production was concerned. Is the general trend of the average production for each month of the year, when considered separately, downward or not during these years? It is conceivable that winter egg production, for example, might have been increased during these years that the total production was decreasing. Was this, as a matter of fact, the case? It is of great importance from the standpoint of the study of methods of breeding for egg production to know what was the effect of the method of selection practiced on the monthly averages throughout the period.

A further set of problems has to do with the correlations which exist in regard to egg production in the different months of the year. On the average, will hens that are high producers in December, let us say, be also high producers in July? It is of the greatest importance, practically as well as theoretically, to know just how closely each month's production is, on the average, associated or correlated with the production in every other month in the year. If a poultry keeper is only able on account of financial or other reasons to test the production of his hens with trap nests during a part of the year, which month or months will give him the best estimate of what the total yearly production will probably be for each hen?

These statements will give some idea of the general standpoint from which this second part of the investigation is undertaken and of the character of the problems with which it deals. It is not desirable to take further space here to set forth in detail the specific problems which are discussed in this portion of the work. These details will be considered in connection with the sections of the paper where the data bearing upon the several problems are discussed.

MATERIAL AND METHODS.

The statistical material which forms the basis of this part of the work is the same as that which was used in Part I. It comprises the trap-nest records of egg production during the pullet years from November, 1899, to November, 1907, at the Maine Agricultural Experiment Station. As was set forth in Part I of this study, the number of hens making complete yearly records in this period was 2,407. A full account was also given of the way in which these records were collected, so it will not be necessary to repeat this here.

Instead, whenever it becomes necessary in the discussion of monthly egg production reference will be made to the account given in Part I.

In this part of the study we are dealing with the monthly production in each month of the years above enumerated. All the statistics are for pullet-year production. The data of the present paper analyze the total annual production into its monthly components. It will be recalled (see Part I, pp. 16–19) that in certain of the years one or another sort of accident occurred to interfere with the egg production of certain months. Due account will be taken of this fact in the discussion of the records in this part of the study.

The detailed data on which this part of the work is based are given in tabular form in Appendix II at the end of this paper. In these tables are given for each month of the period discussed the ungrouped frequency distributions of egg production. It will be seen by referring to the tables that the unit classes of egg production ranging from zero to 31 are arranged horizontally while the vertical units are years and flocks. The first line of Table I may be taken as an illustration of how these tables in general are to be read. From this it is seen that 70 birds were available for record in November, 1899. Of these 70 birds 39 failed to lay at all in November and, therefore, have a zero record. One bird laid one egg during the month; three laid two eggs, and so on. This table gives the ultimate data on which this whole study is based. From these raw data it will be possible for anyone who cares to do so to check up at every point the computed constants.

The biometric methods used in the analysis of the statistical material in this part of the work are in general not different from those which were used in Part I (pp. 20–24). We have made use here, as before, of the ordinary biometric constants and their probable errors. A few words should be said, however, regarding some methods of computation which have been used in the present paper. The constants for monthly egg production have been calculated directly from the ungrouped frequency distributions of the appendix. Since ungrouped distributions were used, and since, further, as will be apparent to anyone studying these distributions, there is no approach to high contact at one end of the distributions at least, Sheppard's correction of the second moment has not been used in calculating the standard deviations. Instead the raw second moment has been used throughout. The computations have been very carefully checked, this being done in most cases independently by two different persons. In nearly every case the tabled constants have been checked independently three or four times. It is hoped that there are no errors in the computations remaining in the published work, although it is impossible in so extensive a piece of statistical work as this to be absolutely sure that minor arithmetical slips have not gone by unnoticed.

MEAN EGG PRODUCTION IN EACH MONTH OF THE YEAR.

In undertaking the discussion of the monthly distribution of egg production it is obvious that the most logical point at which to begin is with the mean or average monthly production for each month of the year. These monthly averages give the fundamental data around which the remainder of the discussion clearly must center.

The values of the mean or average monthly egg production of the Maine station's Barred Plymouth Rock flocks for the period from November, 1899, to November, 1907, are given in Table 1. In this table is given for each month, year, and pen the actual mean number of eggs per bird produced during that month and the probable error of this mean. There is also included for each month, year, and pen the percentage which the actual monthly average for that month is of the total production for the year. Thus, from the first row and column of Table 1 it appears that in November, 1899, the average egg production per bird was 4.31±.48, and that this egg production was 3.1 per cent of the total annual average production for that year. It was pointed out in Part I that in the years 1904 to 1907 the birds were kept in pens of three different sizes, containing, respectively, 50 100, and 150. For these years averages are given in the table for each of these flock sizes. In the last three lines of the table are given the weighted means of egg production for each of these three years. These weighted means were calculated in exactly the same way as were the weighted means for annual production for the same years in Part I (p. 27). The number of birds finishing records in each year is given in the last column of the table.

TABLE 1.—*Average monthly egg production and percentage of total yearly production of Barred Plymouth Rock flocks at Maine Experiment Station, 1899 to 1907.*

Year and pen.	November actual mean.	Per cent of annual.	December actual mean.	Per cent of annual.	January actual mean.	Per cent of annual.	February actual mean.	Per cent of annual.
1899-1900	4.31±.48	3.1	10.29±.73	7.5	16.60±.53	12.1	9.83±.55	7.2
1900-1901	3.08±.40	2.1	8.19±.65	5.7	12.34±.58	8.6	14.27±.45	9.9
1901-2	6.33±.81	4.1	12.02±.82	7.7	15.21±.56	9.8	11.67±.58	7.5
1902-3	5.93±.42	4.4	4.52±.35	3.4	5.94±.43	4.4	9.62±.38	7.2
1903-4		......	5.56±.24	4.7	8.72±.32	7.4	12.27±.29	10.4
1904-5:								
50-bird pens	4.64±.19	3.5	5.63±.30	4.2	10.03±.34	7.5	13.48±.26	10.1
100-bird pens	6.45±.55	5.0	10.67±.52	8.3	11.11±.51	8.6	11.28±.43	8.7
150-bird pens	5.64±.41	5.0	9.17±.46	8.1	10.72±.45	9.5	9.11±.39	8.1
1905-6:								
50-bird pen	6.29±.35	4.5	9.86±.46	7.1	13.83±.38	9.9	14.46±.29	10.4
100-bird pens	5.38±.32	4.2	9.91±.44	7.8	13.27±.38	10.5	13.39±.33	10.5
150-bird pens	3.67±.22	3.1	9.60±.38	8.1	12.44±.34	10.5	11.64±.28	9.8
1906-7:								
50-bird pen	3.25±.25	......	4.70±.33	......	5.70±.33	......	10.49±.32	......
100-bird pens	3.29±.30	......	6.16±.39	......	4.32±.33	......	5.18±.30	......
150-bird pens	4.28±.28	......	7.84±.32	......	4.67±.27	......	6.82±.28	......
1904-5, weighted mean	5.24	4.1	7.49	5.9	10.41	8.2	11.90	9.4
1905-6, weighted mean	4.89	3.9	9.76	7.7	13.07	10.3	12.93	10.2
1906-7, weighted mean	3.70	......	6.46	......	4.87	......	7.41	......

TABLE 1.—*Average monthly egg production and percentage of total yearly production of Barred Plymouth Rock flocks at Maine Experimental Station, 1899 to 1907*—Cont'd.

Year and pen.	March actual mean.	Per cent of annual.	April actual mean.	Per cent of annual.	May actual mean.	Per cent of annual.	June actual mean.	Per cent of annual.
1899–1900	13.04±.47	9.5	16.09±.44	11.8	15.29±.46	11.2	12.53±.51	9.2
1900–1901	17.14±.45	12.0	18.04±.42	12.6	15.45±.45	10.8	14.33±.49	10.0
1901–2	17.17±.47	11.1	18.50±.50	11.9	16.25±.58	10.5	16.88±.40	10.9
1902–3	14.96±.33	11.2	17.71±.32	13.3	17.02±.31	12.7	15.83±.33	11.8
1903–4	17.27±.28	14.6	14.78±.24	12.5	11.63±.23	9.9	12.27±.26	10.4
1904–5:								
50-bird pens	17.98±.23	13.5	15.51±.24	11.7	13.79±.27	10.4	12.59±.26	9.5
100-bird pens	12.23±.42	9.5	15.68±.42	8.7	14.36±.41	11.1	13.34±.46	10.3
150-bird pens	12.02±.41	10.6	13.16±.36	11.6	11.96±.41	10.6	10.22±.42	9.0
1905–6:								
50-bird pen	18.29±.26	13.1	16.48±.23	11.8	11.42±.27	8.6	13.47±.24	9.7
100-bird pens	17.33±.29	13.7	15.08±.26	11.9	10.74±.29	8.5	12.76±.30	10.1
150-bird pens	17.02±.20	14.3	15.20±.20	12.8	10.67±.23	9.0	11.65±.23	9.8
1906–7:								
50-bird pen	17.72±.30	......	17.12±.28	......	14.43±.31	......	11.13±.30	......
100-bird pens	13.96±.31	......	16.41±.28	......	15.23±.30	......	13.11±.30	......
150-bird pens	14.65±.26	......	15.21±.24	......	12.93±.24	......	10.62±.26	......
1904–5, weighted mean	15.33	12.1	14.90	11.1	13.39	10.5	12.08	9.5
1905–6, weighted mean	17.46	13.8	15.52	12.2	10.90	8.6	12.48	9.8
1906–7, weighted mean	15.33	......	16.10	......	14.01	......	11.47	......

Year and pen.	July actual mean.	Per cent of annual.	August actual mean.	Per cent of annual.	September actual mean.	Per cent of annual.	October actual mean.	Per cent of annual.	Total average production.[a]	Number of birds.
1899–1900	11.90±.46	8.7	11.54±.52	8.4	9.30±.52	6.8	6.14±.50	4.5	136.86	70
1900–1901	13.18±.47	9.2	11.66±.52	8.1	10.34±.52	7.2	5.40±.48	3.8	143.42	85
1901–2	14.90±.59	9.6	13.21±.64	8.5	9.29±.75	6.0	3.75±.60	2.4	155.18	48
1902–3	13.57±.33	10.2	12.58±.40	9.4	10.57±.41	7.9	5.40±.39	4.0	133.65	147
1903–4	10.18±.24	8.6	10.03±.27	8.5	9.93±.28	8.4	5.33±.25	4.5	117.97	254
1904–5:										
50-bird pens	10.87±.26	8.2	10.62±.27	8.0	10.82±.31	8.1	7.16±.30	5.4	133.12	283
100-bird pens	11.64±.50	9.0	10.75±.49	8.3	10.62±.55	8.2	5.49±.48	4.2	133.62	92
150-bird pens	9.81±.44	8.7	8.10±.38	7.2	7.49±.41	6.6	5.59±.36	4.9	112.99	140
1905–6:										
50-bird pen	10.49±.27	7.5	9.37±.28	6.7	9.73±.33	7.0	5.80±.33	4.2	139.49	178
100-bird pens	9.84±.31	7.8	7.05±.28	5.6	7.42±.33	5.8	4.66±.31	3.8	126.83	182
150-bird pens	9.09±.25	7.7	6.69±.24	5.6	6.79±.27	5.7	4.29±.24	3.6	118.75	275
1906–7:										
50-bird pen	12.27±.30	......	11.69±.27	......	4.52±.24	......	....	......	113.02	187
100-bird pens	11.48±.32	......	11.66±.33	......	7.99±.32	......	....	......	108.79	185
150-bird pens	10.03±.27	......	9.26±.25	......	4.67±.23	......	....	......	100.98	281
1904–5, weighted mean	10.72	8.4	9.96	7.8	9.88	7.8	6.43	5.1	126.95	515
1905–6, weighted mean	9.70	7.6	7.54	5.9	7.79	6.1	4.81	3.8	126.86	635
1906–7, weighted mean	11.08	......	10.64	......	5.57	......	....	......	106.64	653

[a] Obtained by adding the averages for the several months of the year. The figures in this column do not agree absolutely with those given in Table 2 of Part I, owing to difference in the arithmetical procedures involved. The differences are insignificant in amount and do not affect the results in any way.

Before discussing in detail the individual monthly averages for the several years as given in Table 1, it will be well to have at hand a summarized statement of these data. It is desirable to have the weighted mean production for each month of the year, as based on the whole period covered by our statistics. By taking the data from the whole period in this way and obtaining the weighted mean for each month, it will be possible to get rid of the disturbing effects of the chance fluctuations coming in from year to year to influence the egg production. The weighted mean monthly curve will give us a more just general idea of the normal distribution of monthly production than can be obtained directly from the detailed figures. In calculating such weighted mean monthly productions the proper basis of the weighting is obviously that which has been used previously in this study, namely, to weight each month's production for a given year with the number of birds which made the record.

In calculating the weighted mean monthly figures it will be proper, of course, to include only months in which the egg production was normal. In those months where an accident of any kind interfered with the egg production the average for that month of that particular year obviously should not be included with the records from the other years. Consequently, in determining the weighted means we have omitted all months in which accidents occurred as described in Part I (loc. cit.).

The weighted mean monthly productions obtained in the manner indicated are given in Table 2. Column 1 of this table gives the absolute weighted mean egg production per bird for each month of the year. The second column gives what may be termed the integral curve of mean monthly egg production. The figures in this column are obtained by adding successively to the sum already obtained the average for each particular month as given in column 1. The figures so obtained show what is the average number of eggs produced per bird up to the end of the designated month on the basis of the statistics here under consideration. An example will make the meaning of this column of the table clear. From the entry in column 2 it appears that in the eight years from 1900 to 1907 the average number of eggs per bird laid up to the end of March in the pullet year is 52.23.

In columns 3 and 4 of the table are given the data of columns 1 and 2 in relative or percentage form. Column 3 gives for each month the percentage which the weighted mean production per bird of that month (as given in column 1) is to the total yearly production. Column 4 gives the integral curve of the data of column 3. The significance of the figures in column 4 may again be illustrated by an example. From the data in this column it appears that, on the average, taking the results for the whole period covered by the study, 40.52 per cent of the total number of eggs produced in the pullet year were laid before April 1. Column 5 of the table gives the years from which records were used to obtain the data in the preceding columns. This column shows what years had a particular monthly record omitted because of an accident in that month. Thus, for example, it may be seen that in determining the weighted mean production for the month of November the data from the laying year 1903–4 were not included. Reference to page 17 of Part I of this study shows that the reason for this was that the birds made no record in November, 1903, because they were not moved into the laying house that year until the 5th of December.

Table 2.—*Weighted mean monthly egg production, with monthly and periodical percentages.*

Month.	Absolute weighted mean egg production per bird for month.	Absolute weighted mean egg production from November 1 of pullet year to the end of the month.	Percentage of total yearly production during month.	Percentage of total annual yield between November 1 and end of month.	Years from which data were taken in computing weighted monthly means.[a]
	Number.	*Number.*	*Per cent.*	*Per cent.*	
November	4.63	4.63	3.59	3.59	1899, 1900, 1901, 1902, 1904, 1905, 1906.
December	8.91	13.54	6.91	10.50	1899, 1900, 1901, 1904, 1905.
January	11.71	25.25	9.08	19.58	1900, 1901, 1902, 1904, 1905, 1906.
February	10.87	36.12	8.44	28.02	1900, 1901, 1902, 1903, 1904, 1905, 1906, 1907.
March	16.11	52.23	12.50	40.52	1900, 1901, 1902, 1903, 1904, 1905, 1906, 1907.
April	15.85	68.08	12.30	52.82	1900, 1901, 1902, 1903, 1904, 1905, 1907.
May	13.92	82.00	10.80	63.62	1900, 1901, 1902, 1903, 1904, 1905, 1907.
June	12.46	94.46	9.67	73.29	1900, 1901, 1902, 1903, 1904, 1905, 1906, 1907.
July	10.87	105.33	8.44	81.73	1900, 1901, 1902, 1903, 1904, 1905, 1906, 1907.
August	9.84	115.17	7.64	89.37	1900, 1901, 1902, 1903, 1904, 1905, 1906, 1907.
September	8.19	123.36	6.36	95.73	1900, 1901, 1902, 1903, 1904, 1905, 1906, 1907.
October	5.50	128.86	4.27	100.00	1900, 1901, 1902, 1903, 1904, 1905, 1906.
Total	128.86	....	100.00	....	

[a] In the years for which data are not included in any particular month either an accident interfered with the egg production in that month or there was no record for that month in those years.

With the fundamental data given in Table I of the appendix and Tables 1 and 2 of this section in hand, we may proceed to the discussion of the specific problems with which this part of the work has to do.

THE MONTHLY DISTRIBUTION OF EGG PRODUCTION.

The first question which needs to be considered is as to the general form of the monthly egg-production curve. In the discussion of this matter here use will be made only of the Barred Plymouth Rock data already presented. The data given in column 1 of Table 2 may be taken as the basis from which to gain a general idea of the form of the monthly egg distribution polygon. In figure 1 these data are shown graphically.

It may be noted from the data given in Table 2 and figure 1 that—

1. The form of the monthly egg-production polygon is in general somewhat like that of a frequency curve of variation. The polygon has a single peak, and from that point slopes down toward the base line on both sides. The peak comes at a point not far from the middle of the laying year with the limits here used.

2. Considering the form of the polygon somewhat more in detail, we note that the line starts from a low point in November and rises rather rapidly and in almost a straight line to January. The slope of the line from January to February is downward. In other words, there is an indentation in the ascending limb of the egg-production polygon in the month of February. This is a very characteristic feature of the distribution of egg production, not only observed with the birds here under discussion but also in published records from other sources.

A study of Table 1 shows that this is generally true for every year covered by the investigation. While the February mean production is not necessarily actually lower than the January, though this is true in many cases, there is a perceptible slowing of the rate of increase in egg production which has obtained up to that time. The most probable interpretation of this appears to us to be that the February indentation in the egg-production curve represents a rest or reaction after the winter laying and in anticipation of the heavy March and April production. It marks the completion of a laying cycle on the part of those birds which have been laying during the winter months. After the maximum is reached in March, the descending limb of the egg-production polygon begins. This limb is very nearly a straight line over its whole extent. There is, however, a slight but characteristic indentation to be noted in May. This, like the February falling off in production, is probably to be regarded as the result of a reaction after a period of heavy laying. It marks the completion of the spring laying cycle. The May depression is, further, an expression of the normal brooding season following the heavy laying of March and April. From May on the line descends in a nearly straight course to a low point in the last month of the laying year, October.

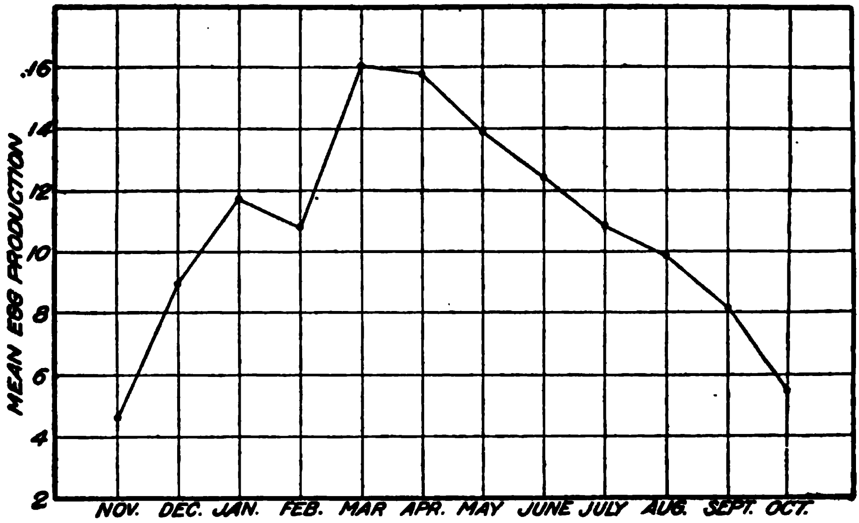

FIG. 1.—Diagram showing the weighted mean monthly egg production for each month of the pullet year.

3. The slope of the ascending limb of the production curve is steeper than that of the descending limb. The rise in egg production to the maximum is more rapid than is the descent from that point.

The curve of mean monthly egg production is shown in integral form in figure 2. This method of dealing with the data brings out some additional points. The curve shown in this figure is the graph of columns 2 and 4 of Table 2.

From figure 2 and the data in Table 2 we note—

1. The average egg production for the whole pullet year, taking the whole period covered by the statistics into consideration, was 128.86 eggs.

2. Of this total annual production, 28.02 per cent (or 36.12 eggs) is produced in the winter months (November 1 to March 1). In this third of the year only about two-sevenths of the total number of eggs are laid.

3. In the period from November 1 to July 1, 73.29 per cent of the total number of eggs is produced. Or, in other words, in the first two-thirds of the laying year nearly three-fourths of the year's eggs are laid.

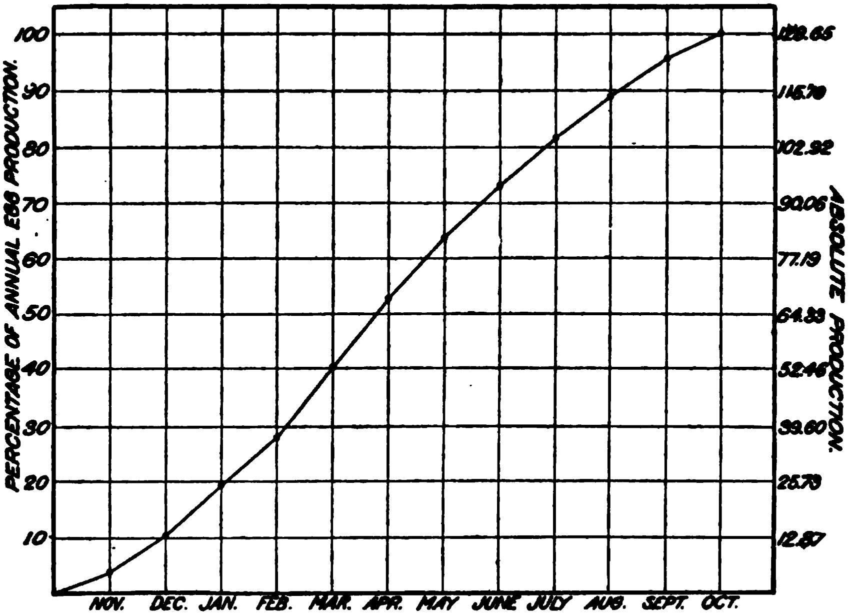

FIG. 2.—Integral curve of weighted mean monthly egg production, showing the absolute and relative number of eggs laid from the beginning of the laying year up to the end of each month.

4. From March 1 to June 1, 35.60 per cent of the total number of eggs is produced. In this particular quarter of the laying year a little more than a third of the eggs are laid.

5. The figures given in Table 2 are likely to prove useful in future discussions of egg-production statistics. They furnish an accurate and trustworthy datum with which other figures may be compared. The need for such a trustworthy basis for comparative discussion has been keenly felt in studies on egg production.

A question which needs more particular discussion than has so far been given it in this paper is as to exactly where in the laying year the maximum of productivity per unit of time occurs. Does this maximum point occur at the same time each year, or does it vary irregularly from year to year?

It is apparent from Table 2 that if the weighted mean figures for the whole period covered by the investigation be taken, the month of maximum production is March. The weighted mean for April, however, falls below that for March by only 0.26 egg—a very small amount. The facts regarding the individual years may most clearly be shown graphically. In figure 3 are platted the mean productions for the months of March and April of each year. Since the maximum production falls in one or other of these months in the present statistics, it will not be necessary to consider other months in this connection.

From this diagram it is clear that neither March nor April has uniformly held the place as the month of maximum production during the period covered by the investigation. In the earlier years (1899–1900 to 1902–3) April had a larger average than March and was the month of maximum production. From 1903–4 to 1905–6, inclusive, March had a larger mean production than April. The relation is reversed again in the last year covered by the statistics (1906–7), though in this year the averages for March and April are very nearly the same.

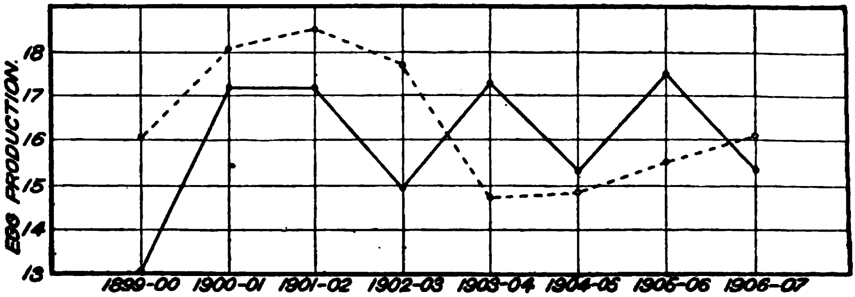

FIG. 3.—Diagram showing the fluctuations of mean monthly egg production in the two months of maximum production, March and April.

It further appears that the change in the month of maximum production which occurs as we pass from the laying year 1902–3 to 1903–4 is entirely due to a marked drop in the average April production for 1903–4 and subsequent years. The mean March production holds at about the same general level throughout. This change appears to have been due to the fact that in the fall of 1903 the birds were for the first time put into a "curtain-front" house. In the earlier years of the experiment the birds had been housed in tight, warmed houses.

Putting all the data together the following statement may be made: So long as the birds were kept in warmed, tight houses the month of maximum average egg production was April. When the change to the curtain-front system of housing was made the April average immediately dropped below that of March, the latter then becoming the month of maximum production. The highest weighted mean monthly average is that for March. This arises because of the larger number of birds and consequently greater weight given to the averages in the later years.

Another question to be considered is as to which is the month of minimum average production. This clearly is either November (at the beginning of the laying year) or October (the end of the year). The weighted mean figures of Table 2 and figure 1 show the month of minimum average production over the whole period to have been November. The weighted mean production for that month is very nearly one egg lower than that for October.

Turning to the records for individual years, the facts are shown graphically in figure 4. In this diagram are platted the October and November means for each year, except the November record for 1903–4 and the October record for 1906–7. As has been pointed out already, there were no records for these months.

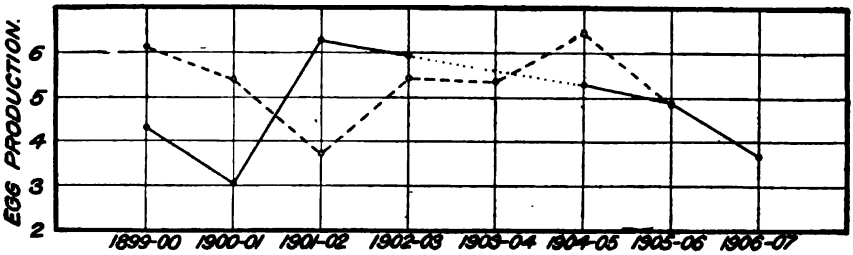

FIG. 4.—Diagram showing the fluctuation of mean monthly egg production in the two months of minimum production, October and November.

From this diagram it appears that there is no steady tendency for the November mean production to be lower than the October, or vice versa. In different years either month may show the lower production. The only conclusion that can be safely drawn from the data is that either one or other of these two months shows the minimum production for the year—which one depending upon circumstances.

VARIATION IN EGG PRODUCTION IN EACH MONTH OF THE YEAR.

In discussing the variability in egg production in the different months of the year use will be made of the same variation constants as in Part I of this paper, namely, the standard deviation and the coefficient of variation.[a] It will be found to be the case with the monthly distributions, just as with the annual, that the coefficient of variation is the more trustworthy constant on which to base one's judgment as to the actual degree of existing variability in this character. The reason for this is that the absolute average production is so different in the different months. In consequence of this the absolute amount of "scatter" in the distributions is changed.[a]

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[a] A description of the significance of these two variation-measuring constants—standard deviation and coefficient of variation—is given in Part I, page 27, and need not be repeated here. It suffices merely to recall that the standard deviation is the measure of absolute variation in terms of eggs, whereas the coefficient gives the relative variation in per cent.

In calculating the variation constants for the monthly distributions the same methods were used as have been described in Part I. Just as in the case of the means (cf. p. 87, supra), so in the case of the variation-measuring constants, weighted average figures have been taken for the three laying years, 1904–5, 1905–6, 1906–7, where the birds were kept in flocks of different sizes. The weighting was done here, as before, on the basis of the number of birds in each pen.

On account of the fact that the standard deviation has comparatively little significance in discussions of variation in egg production, it has not seemed necessary or advisable to take the time to calculate the probable errors for all the standard deviations of the monthly distributions. The probable errors have been determined, however, for the coefficients of variation.

The data for variation in monthly egg production are given in Tables 3 and 4. Table 3 contains the standard deviation in egg production for each month covered by our statistics and Table 4 the coefficient of variation.

TABLE 3.—*Standard deviation in egg production of Barred Plymouth Rocks for each month of the laying year.*[b]

Year and flock.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
1899–1900	6.00	9.05	6.59	6.79	5.81	5.43	5.72	6.28	5.68	6.44	6.39	6.26
1900–1901	5.40	8.83	7.96	6.13	6.16	5.68	6.18	6.75	6.38	7.05	7.16	6.62
1901–2	8.35	8.46	5.79	5.92	4.81	5.13	5.99	4.07	6.08	6.55	7.75	6.15
1902–3	7.60	6.32	7.67	6.76	5.86	5.74	5.65	5.96	5.96	7.28	7.31	7.06
1903–4	......	5.60	7.46	6.93	6.54	5.67	5.53	6.16	5.75	6.31	6.72	5.81
1904–5:												
50-bird pens	4.64	7.59	8.41	6.50	5.80	5.97	6.85	6.49	6.53	6.77	7.66	7.40
100-bird pens	7.77	7.39	7.22	6.11	5.93	5.99	5.76	6.49	7.12	6.91	7.86	6.78
150-bird pens	7.23	8.10	7.89	6.78	7.14	6.37	7.24	7.44	7.80	6.71	7.17	6.25
1905–6:												
50-bird pens	6.83	9.10	7.46	5.64	5.15	4.61	5.28	4.83	5.25	5.57	6.53	6.58
100-bird pens	6.48	8.87	7.65	6.52	5.75	5.15	5.76	5.92	6.23	5.58	6.03	6.19
150-bird pens	5.47	9.26	8.44	6.80	4.89	4.86	5.64	5.62	6.14	5.92	6.57	6.02
1906–7:												
50-bird pens	5.06	6.77	6.75	6.55	6.01	5.73	6.23	6.05	6.12	5.40	4.85	......
100-bird pens	6.06	7.90	6.57	6.08	6.17	5.63	5.98	5.99	6.46	6.57	6.45	......
150-bird pens	6.92	8.01	6.72	6.89	6.58	5.94	5.95	6.45	6.63	6.24	5.61	......
1904–5, weighted mean	5.90	7.69	8.06	6.51	6.19	6.08	6.76	6.75	6.98	6.78	7.56	6.98
1905–6, weighted mean	6.14	9.10	7.94	6.39	5.21	4.87	5.57	5.48	5.92	5.72	6.58	6.23
1906–7, weighted mean	6.14	7.62	6.69	6.56	6.30	5.79	6.04	6.21	6.44	6.09	5.63	......

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[a] For a discussion of this point see Part I of this study, page 27.

[b] Because of the fact that the standard deviation is not the significant measure of variation in egg-production statistics, probable errors have not been calculated for the constants in this table. From the data given in this table and in Table 1 anyone can easily calculate the probable error of any standard deviation in this table. In general, the probable error of the standard deviation will be approximately 71 per cent of the probable error of the corresponding mean as given in Table 1.

TABLE 4.—*Coefficients of variation for the egg production of Barred Plymouth Rocks for each month of the laying year.*

Year and flock.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.
1899-1900	139.10±17.50	87.99±8.01	39.70±2.60	69.05±5.50	44.58±3.00	33.79±2.13	37.39±2.41	50.13±3.50	47.73±3.27	55.82±4.05	68.69±5.46	101.92±10.19
1900-1901	175.18±22.04	107.83±10.17	64.53±4.53	42.93±2.60	35.96±2.09	31.49±1.78	40.00±2.38	47.11±2.93	48.39±3.03	60.46±3.49	69.25±5.01	122.68±12.71
1901-2	131.84±19.20	70.37±6.83	38.08±2.98	50.72±4.30	28.02±2.07	27.74±2.05	36.87±2.86	24.12±1.75	40.79±3.24	49.57±4.17	83.39±8.88	163.98±28.51
1902-3	128.17±10.44	139.60±12.15	129.13±10.58	70.25±3.90	39.14±1.76	32.39±1.40	33.21±1.44	37.66±1.68	38.27±1.70	57.87±2.94	69.19±3.81	130.67±10.80
1903-4	....	100.71±5.25	85.63±4.03	56.48±2.16	37.88±1.29	38.34±1.31	47.53±1.71	50.22±1.84	56.50±2.16	62.86±2.52	67.68±2.80	109.03±7.13
1904-5:												
50-bird pens	160.92±11.34	134.82±8.23	83.85±3.69	48.23±1.66	32.25±1.00	38.50±1.24	49.68±1.72	51.52±1.81	60.07±2.23	63.75±2.43	70.81±2.84	103.37±5.19
100-bird pens	120.57±10.62	69.24±4.82	64.99±4.39	54.17±3.39	48.46±2.92	38.16±2.16	40.09±2.29	48.65±2.94	61.16±4.02	64.28±4.32	74.05±5.33	123.52±13.82
150-bird pens	128.21±10.70	88.27±5.69	73.63±4.26	74.46±4.36	59.42±3.13	48.38±2.36	60.55±3.21	72.76±4.03	79.51±4.82	82.81±5.14	95.64±6.48	111.86±8.43
1905-6:												
50-bird pens	108.59±7.11	92.33±5.43	53.93±2.42	39.02±1.59	28.17±1.68	27.96±1.07	46.20±1.98	35.85±1.44	50.06±2.19	59.40±2.77	67.13±3.31	113.45±7.67
100-bird pens	120.25±8.39	89.48±5.11	57.64±2.63	48.72±2.09	33.17±1.30	34.17±1.34	53.63±2.38	46.41±1.96	63.28±3.00	79.10±4.20	89.44±5.10	132.77±9.98
150-bird pens	148.96±9.99	96.37±4.69	67.83±2.70	58.38±2.18	28.76±0.89	31.98±1.01	52.88±1.90	48.25±1.68	67.56±2.69	88.54±4.08	96.83±4.72	140.27±8.96
1906-7:												
50-bird pens	155.77±13.14	144.08±11.41	118.52±8.07	62.44±2.91	33.93±1.31	33.45±1.29	43.18±1.76	54.37±2.39	49.88±2.13	46.20±2.50	107.40±6.12	....
100-bird pens	183.96±17.98	128.28±9.32	152.01±12.64	117.33±7.97	44.19±1.83	34.31±1.34	39.28±1.58	45.72±1.91	56.28±2.52	56.36±2.53	80.75±4.30	....
150-bird pens	161.87±11.50	102.15±5.11	143.93±9.29	100.99±5.01	44.90±1.51	39.02±1.28	46.02±1.57	60.74±2.28	66.07±2.57	67.37±2.65	120.29±6.75	....
1904-5, weighted mean	144.82	110.45	77.70	56.42	42.53	41.13	50.92	56.78	65.55	69.03	78.14	109.28
1905-6, weighted mean	129.41	93.26	61.01	50.18	29.86	31.48	51.22	44.25	61.43	77.67	86.39	130.60
1906-7, weighted mean	106.38	121.56	138.94	94.58	41.56	36.09	43.30	54.66	58.66	58.19	105.40	....

The first point which it is necessary to take up is in regard to the general trend of the variability in egg production in the different months of the year. In order to do this satisfactorily it is desirable to have in hand the weighted average figures for each month based on the whole experience covered by the statistics (1899 to 1907). It is as necessary to have these weighted figures in the case of variation constants as it was in the case of the means. They smooth out the insignificant fluctuations of individual years. Such weighted average values for the standard deviations and coefficients of variation are given in Table 5. The weighting is again made on the basis of the number of individuals involved.

TABLE 5.—*Variation in monthly egg production: Weighted mean standard deviations and coefficients of variation based on total period 1899–1907.*[a]

Month.	Weighted mean standard deviation.	Weighted mean coefficient of variation.
	Eggs.	*Per cent.*
November	6.20	146.40
December	8.52	99.63
January	7.78	68.82
February	6.53	65.75
March	5.94	37.76
April	5.82	37.03
May	6.17	44.72
June	6.09	49.55
July	6.28	57.94
August	6.29	65.96
September	6.63	85.58
October	6.48	121.30

[a] In calculating these mean figures no month was included which was in any respect abnormal. By reference to column 5 of Table 2, the years which contributed data to the averages for each month may be determined.

The data given in Table 5 are shown graphically in figures 5 and 6. With these data in hand we may proceed to discuss some of the problems regarding variability in monthly egg production. It has been shown in Part I (pp. 28, 29) that a certain degree of variation in annual production is fairly constant and characteristic for the flocks here under consideration. Is this same degree of relative variability characteristic for each month of year? Or is some other definite degree of variability more or less characteristic for the monthly distribution? Or is it the case that the flocks show greater variability in certain seasons of the year than in others? If the last is true, how are these differences distributed?

We may in this connection consider first the standard deviations. An examination of the data in Table 5 and figure 5 shows that starting at a point of maximum absolute variation in December there is a steady and rather rapid decrease until the minimum is reached in April. From that point on to the end of the laying year in October there is a very much more gradual but still distinct increase in the value of the standard deviation. The standard deviation of egg production in the month of November does not fall into this scheme shown by the remaining months of the laying year. If it did it should have a higher value than that for December, whereas, as a matter of fact, the standard deviation for November is just about the same as that for May and is very much below that for December. Leaving this single month out of account for the moment, however, it is plain

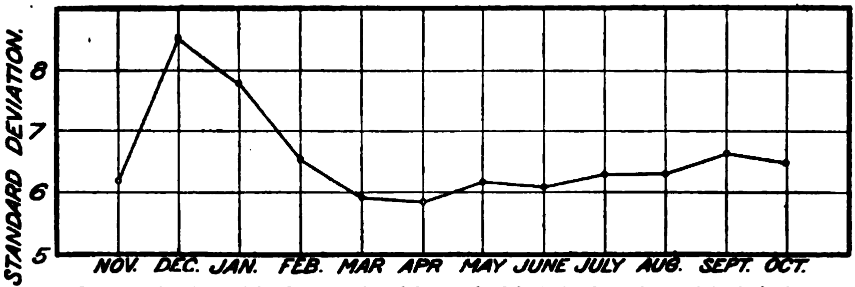

FIG. 5.—Diagram showing weighted mean value of the standard deviation for each month in the laying year.

that the curve of absolute variability in egg production is in a general way similar to the curve of mean monthly egg production turned upside down. Where the curve of mean monthly production increases rapidly the curve of absolute variability in egg production decreases rapidly (December to April). On the other hand, where the curve

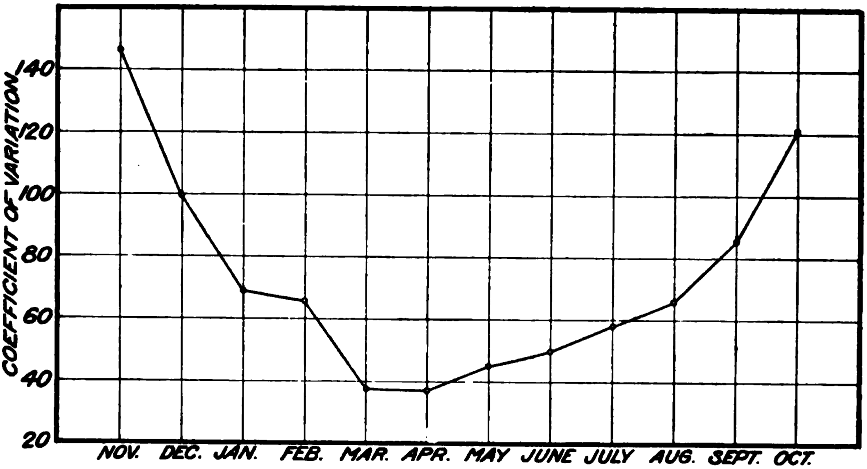

FIG. 6.—Diagram showing weighted mean value of the coefficient of variation for each month in the laying year.

of mean production decreases slowly the curve of absolute variability in egg production increases also slowly. The exception afforded by the month of November to this rule is due to the fact that there is a very high frequency of zero production in the November distributions. (See Appendix II, Table I.) There are many hens which do not begin to lay in November. Hence there is very little absolute "scatter" to the distribution for this month. Consequently it may be said that while as a general rule the absolute variation in egg production is greater when the average production per bird is low, this relation fails to hold when the laying gets so poor that the major part of the flock lays no eggs at all, thus putting a large frequency on one base element, viz, zero. This point will appear more clearly when the form of distribution for the individual months is taken up (p. 126).

Turning to a consideration of the curve of relative variability in egg production in the different months as given by the data in the second column of Table 5 and in figure 6, we see the same relation as is given by the standard deviations, but in a much more pronounced and distinct form. The curve starts with a maximum relative variability in November and falls steadily and rapidly to a minimum in March and April. It then rises gradually and in almost a straight line to August. From August to the end of the year in October the line of the coefficient of variation rises at a still sharper angle to the base. The data furnished by both absolute and relative measures of variation lead to the general result that when flocks are laying well there is a great deal of uniformity in regard to their laying (i. e., little variation), whereas when they are laying poorly they exhibit a great deal of variation.

There are one or two matters of detail in regard to these curves of variation in monthly egg production which it is desirable to discuss briefly. First, in respect to the time of the year in which the maximum degree of variability in egg production is exhibited, it is of interest to note that this time is at the beginning of the pullet-laying year rather than at the end. Thus, in figure 5 November and December show higher values of the coefficient of variation than do September and October. The same is true for the standard deviations save only for the exception made by November.

The month of minimum variability, both absolute and relative, is April. The difference, however, in the variability in production between March and April is so small as to be insignificant in the weighted figures or in any single year. It is of some interest to note, though, that with the single exception of the year 1901–2 the standard deviation is lower for April than for March (see Table 3). In two years—1903–4 and 1905–6—the coefficient of variation is greater in April than in March. There is clearly no definite change after the year 1902–3 in the degree of absolute or relative variability, such as was seen to be the case with the mean production (see p. 92).

From the data given in Table 2 of Part I (p. 28) it is possible to determine the following two values based on the whole experience covered by our statistics (1899–1907):

Weighted mean standard deviation for annual egg production = 41.74 eggs.

Weighted mean coefficient of variation for annual egg production = 34.21 per cent.

Comparing these with the monthly variabilities it is seen that, as would be expected, (*a*) the absolute variation or "scatter" is much greater for the annual distributions than for any of the monthly. (*b*) Relatively, however, there is no month which on the average shows so low a variability in proportion to its mean as does the production of the whole year. April comes nearest to this, but it falls short nearly 3 per cent.

THE NATURAL DIVISIONS OF THE LAYING YEAR.

It will undeniably be advantageous, in studying certain phases of the problem of egg production, to endeavor to use a time unit which conforms to the natural periodicity displayed by hens. In recent years it has been the custom in the discussion of egg production to make the unit one year. This custom has been followed in the work of the Maine station, in the egg-laying competitions in South Australia, which have excited world-wide interest, and by many other institutions and experimenters. It is safe to say, however, that all students of the subject of egg production have felt that the year was not in all respects an ideal unit for such studies. A serious objection to it is immediately apparent if one makes a close study of individual egg records. The total number of eggs laid by a bird in a year gives in reality an inadequate and incomplete idea of her egg-producing ability. Birds which make the same yearly total records are by no means always equivalent as egg producers.

The plan followed at the present time[a] in the investigations in progress at the Maine station breaks the laying year up into four parts. The first of these includes the months of November, December, January, and February. Broadly speaking, this is the period of winter laying and is so designated. The second period includes the months of March, April, and May. This, broadly speaking, obviously corresponds to the breeding season. The third period includes the months of June, July, and August, and is called the summer period. Finally, the fourth period includes the months of September and October, and is the period in which molting and its associated drop in egg production commonly occur. In future discussions of egg production by the present writers it is proposed, wherever necessary or desirable, to consider separately the egg production in each of these periods. By this method it will be possible to compare, for example, the production in the winter-laying period of different lots of birds, or their ability to lay during the breeding season, and so on.

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[a] See, for example, Maine Agricultural Experiment Station Bulletin 166.

The justification for the conclusion that this division of the year is in general a natural one and corresponds to a real cyclical periodicity in egg production is in considerable measure to be found in the facts regarding mean monthly egg production and variation in this character set forth in this and the preceding section of the paper. The winter-laying period is a period characterized by rapid increase in mean production associated with a relatively equally rapid decrease in variability, both absolute and relative. In this period a large part of the flock falls in the A component of the monthly distributions (see p. 142). This laying period is, strictly speaking, not a part of the natural or normal reproductive cycle of the hen. Egg laying in this part of the year is something which during domestication has been added on, as it were, to the natural reproductive activity of the wild *Gallus*. It is a result of "forcing" or special stimulation. From the evolution standpoint, egg production in these months is a comparatively recent acquisition. Such being the case, the greater variability observed in winter laying is only what would be expected.

The limits of this artificial winter cycle of egg production are fairly well defined. It begins with the beginning of the laying year. Its other limit is marked by the slacking up in egg production which occurs in February (see fig. 1). This slacking up in February, which appears to be a characteristic of egg production generally, is to be explained, we believe, chiefly if not entirely as the result of the ending of the winter cycle by the majority of birds which have laid during the early winter. Such birds rest for a period at about this time before beginning the spring laying cycle. Of course it must be understood that these statements are made only with reference to what might be called the general or average course of events. Particular birds may form exceptions in their laying. Many birds, of course, have no proper winter cycle of laying at all. They begin to lay for the first time in January or February, and keep on laying without any large break straight through the spring cycle.

The next period (March, April, and May) is the natural laying season. It corresponds to the egg-laying part of the natural reproductive cycle exhibited by the wild *Gallus*. This being the case, we should expect the egg production in the domesticated birds also to be at a maximum at this time. They ought further to show a minimum degree of variation in egg production at this time, because nearly every individual which is physiologically capable of ovulation is laying, or has laid very recently, and is broody. Naturally, therefore, a high mean and a low variability in production are exactly what we find characterizing the laying in each of the months in this period.

The third period (June, July, and August) is characterized by a gradually falling mean production and a variability gradually increasing, but still much lower than that for the winter period. This is the period in which rearing of the chickens naturally occurs, and it also represents an extension of the breeding season. It is a period in which laying naturally (i. e., without the forcing or stimulation of domestication) occurs in some degree. We are informed[a] by Mr. J. H. Burkill, of the Indian Museum in Calcutta, that in the central provinces of India the breeding season of *Gallus ferrugineus* Gmel. is said to last until November, beginning in the spring. Similarly the breeding season of *Gallus sonneratii* Temminck in the central provinces lasts from March to November.

The fourth period (September and October) is not easily separated from the third in respect to laying, but in general it is the period of molting, or, if the process has not actually begun, of preparation for molting. It is characterized by reduced laying and markedly increased variability. The variability in egg production in this period is not so great, however, as in the winter laying period, which falls entirely outside the natural reproductive cycle.

CHANGES IN MONTHLY EGG PRODUCTION DUE TO SELECTIVE BREEDING.

As has been stated earlier in the paper (p. 84), it is a matter of prime importance to examine the constants of monthly egg production with reference to their bearing on the problem of selection. It is the purpose of this section to discuss this matter. Specifically the attempt will be made to determine whether during the period in which selection for egg production was practiced[b] there was any definite steady trend of (*a*) the mean monthly production, or (*b*) the absolute variability, or (*c*) the relative variability in monthly production either upward or downward, each single month being considered separately.

The most direct and simple way to approach this problem is, without any doubt, to plat the values of each constant (mean, standard deviation, or coefficient of variation) for each month of the years covered by the statistics as given in Tables 1, 3, and 4, using weighted mean values for the last three years, 1904–1907. To obtain a just idea of the general trend of the zigzag lines so obtained it will be necessary to fit to each of them a line by some adequate method of curve fitting. Then by inspection of the fitted line, keeping in mind the values of the probable errors of the constants under discussion, it will be possible to conclude whether there has been any steady, definite change in that constant as selective breeding has proceeded. This is the method which will be followed. All the lines to be given were fitted by the method of least squares.

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[a] In litt.

[b] For a detailed account of the method of selective breeding followed, see Part I, p. 12.

EFFECT ON AVERAGE MONTHLY PRODUCTION.

We may first examine the mean production for each month with reference to whether it increased or decreased with continued selection for higher annual production. The fundamental data on this point are given in Table 1.

In figures 7 and 8 are given the data of Table 1 in diagrammatic form. Figure 7 includes the observed means and best fitting straight lines for the egg production of the months of November to April, inclusive. In the same way figure 8 shows the observed means and their fitted straight lines for the months of the second half of the laying year, May to October, inclusive. In all cases the weighted mean figures are used for the last three years, 1904–1907.

The equations to the straight lines in figures 7 and 8 are as follows, y denoting mean monthly production and x number of years since the laying year 1898–99:

November	$y=4.68+0.026x$	May	$y=16.69-0.544x$
December	$y=9.72-.375x$	June	$y=15.34-.412x$
January	$y=15.72-1.072x$	July	$y=13.997-.465x$
February	$y=12.33-.242x$	August	$y=13.05-.479x$
March	$y=15.19+.172x$	September	$y=11.11-.449x$
April	$y=17.86-.313x$	October	$y=5.37-.011x$

From these diagrams (figs. 7, 8) the following points are to be noted:

1. With the exception of the months of November and March, there is clearly observable in each month a downward tendency or trend of the line of mean monthly egg production. In other words, the mean egg production in ten months out of the twelve shows exactly the same phenomenon as does the total annual production during the period of continued selection (see Pt. I, pp. 38–43). The amount or degree of this downward trend differs in different months, being statistically insignificant in some months and quite certainly significant in others. January shows the greatest decrease in mean production. October exhibits the smallest decrease of any of the months showing any decline whatever. The line for this month is sensibly horizontal.

2. Of the two months which form apparent exceptions to the rule that the mean monthly production decreased during the period of investigation, neither can justly be regarded as affording a real exception. The line for November is certainly horizontal within the limits of the probable errors involved. There was neither a decrease nor an increase in the mean production in this month during the years studied. In the case of March the line slopes upward a little more definitely than does that for November, but still it can hardly be considered as deviating significantly from horizontality when the

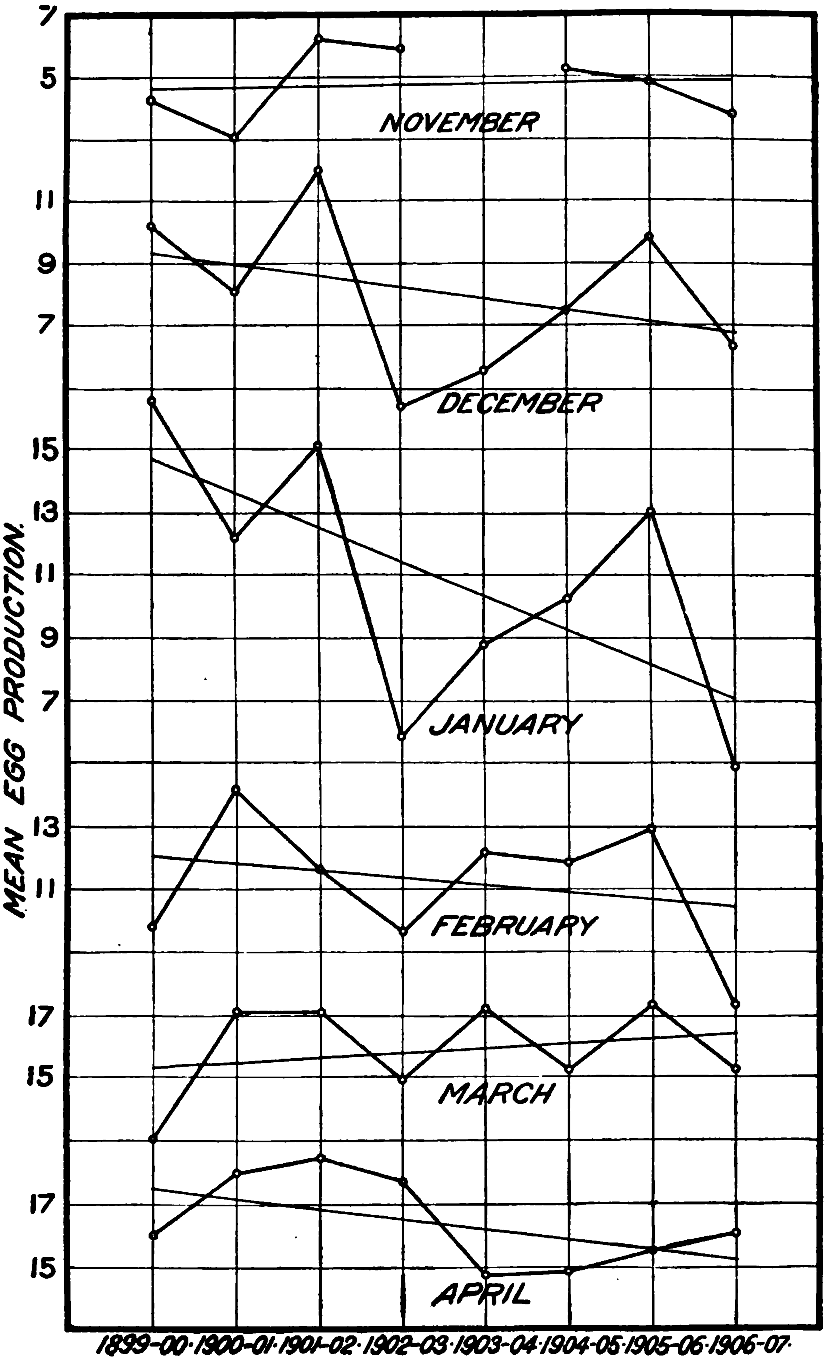

FIG. 7.—Diagram showing the course of the observed mean egg production in each of the months of November to April, inclusive, 1899–1907.

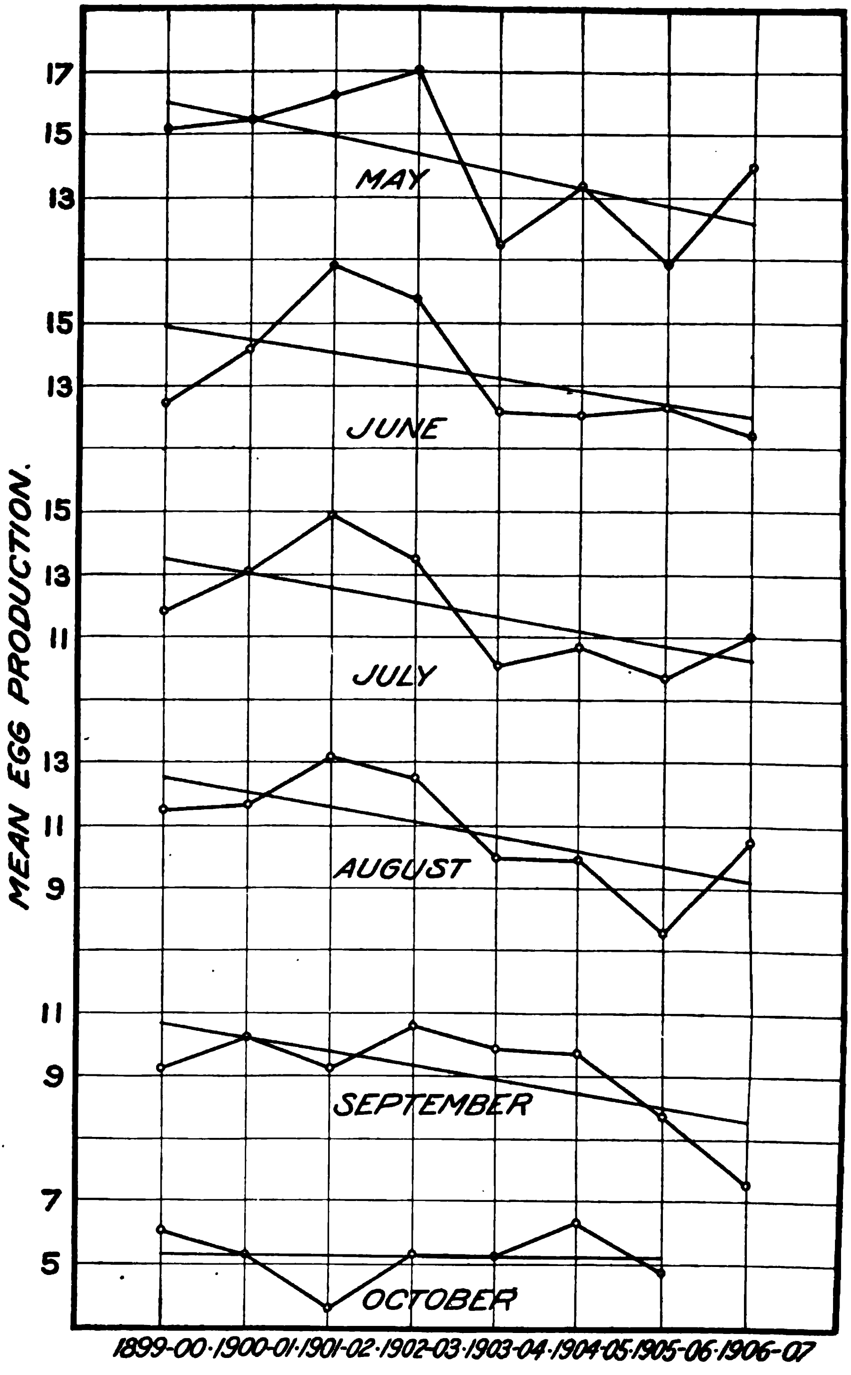

FIG. 8.—Diagram showing the course of the observed mean egg production in each of the months of May to October, inclusive, 1899–1907.

probable errors of the several means are taken into account. That there should have been an insignificant change in the mean March production is exactly what would be expected when it is remembered that this is the natural season of heaviest laying. In this period the egg production is very little affected either by breeding or by environmental influences.

3. In Part I of this study (pp. 40, 41), in discussing the general trend of average annual egg production under the influence of selective breeding, modifications or corrections of the observed means were made to allow for the influence of unavoidable accidents which were held to have affected adversely the egg production in particular months of certain years. Regarding these modifications the following general statement was made (loc. cit., p. 38):

> We may next proceed to modify the constants, for the influence of accidents and the like, from the actual values they show. In every case we can be sure of the general direction in which such modification should be applied. As to what its exact amount in each case should be there are, of course, no criteria. But if we make the modifications relatively large, we shall establish what may be regarded as a series of upper limiting values for the constants. We may then fairly conclude that had all the conditions remained normal throughout the period covered by the data the values exhibited by the constants would have fallen somewhere between the limits set by the actual and modified values. While such a method can not give us precise values, it is capable of showing what the general trend of the data is.

It is apparent that the significance of this reasoning ultimately rests on the question of whether the modifications made are sufficiently large to establish what are in reality upper limiting values. In Part I the attempt was made to show that the modifications used were sufficiently large and that if they were in error at all it was in being too large. It was, however, impossible to demonstrate that this was the case without the detailed monthly data in hand. These data we now have, and they are shown graphically in figures 7 and 8.

It is neither necessary nor desirable to take the space to show in detail that each of the modifications used was sufficiently large, for if anyone interested will, for himself, add to the averages for the individual months as shown in figures 7 and 8 the modifications given in Table 5 of Part I, platting the resulting points on the diagrams of figures 7 and 8, he will see at once that the modifying factors used were very much larger than strict fairness demanded. This may be shown specifically by taking up in detail a single example. In the year 1905–6, 50 per cent of the recorded April production (16.48 eggs) and of the recorded May production (11.42 eggs) in the 50-bird pens was added to allow for an accident (see Pt. I, p. 41). This results in a modified April mean of 24.72 and a May mean of 17.13. Now Table 1 and figures 7 and 8 show that the highest April mean production ever reached in the eight years' trap nesting was only 18.50 eggs (1901–2) and the highest May mean was 17.02 (1902–3). In other words, the modified April mean is some 6 eggs higher than the highest April mean ever observed for the station's flocks, while the modified May mean was equal to the highest May mean observed. There can be no doubt that the modifications used were in every case sufficiently large.

EFFECT ON ABSOLUTE VARIATION AS MEASURED BY THE STANDARD DEVIATION.

We may turn next to the examination of the changes in absolute variability in egg production as measured by the standard deviation which occurred in the period covered by the statistics. It has been shown in Part I (p. 45) that neither the absolute nor the relative variability in total annual egg production sensibly decreased with continued selection. We have now to determine whether the variability in egg production in any months of the year showed the effect of selection by becoming less as the selective breeding was continued. We will first discuss absolute variability as measured by the standard deviation, and later relative variability as measured by the coefficient of variation. The fundamental data for the treatment of absolute variability are given in Table 3, which records the standard deviation for each month. These data are platted in figures 9 and 10 and the observed values are fitted by the method of least squares with straight lines just as was done in the case of mean egg production. As before, weighted mean values were used for the years 1904 to 1907.

The equations to the straight lines in these figures are as follows, y denoting standard deviation and x number of years since the laying year, 1898–99:

November	$y=6.58-0.020x$	May	$y=5.86+0.016x$
December	$y=8.46-.139x$	June	$y=5.88+.017x$
January	$y=6.88+.086x$	July	$y=5.85+.066x$
February	$y=6.41+.019x$	August	$y=7.03-.112x$
March	$y=5.67+.042x$	September	$y=7.39-.112x$
April	$y=5.48+.015x$	October	$y=6.40-.010x$

From these diagrams (figs. 9, 10) the following points are to be noted:

1. There is less regularity in the trend of the variability curves than was observed in the case of the curves for the means. While in the majority of cases the standard deviation increases more or less during the course of the experiment, there are five cases in which it decreases by a greater or less amount. It should be said, however, that in nearly all of these cases the change, whether up or down, is very small in amount. The lines for the standard deviation run in all cases not far from the horizontal. The fair conclusion would seem to be that, during the period covered by the statistics when selective breeding for total annual egg production was practiced, it had prac-

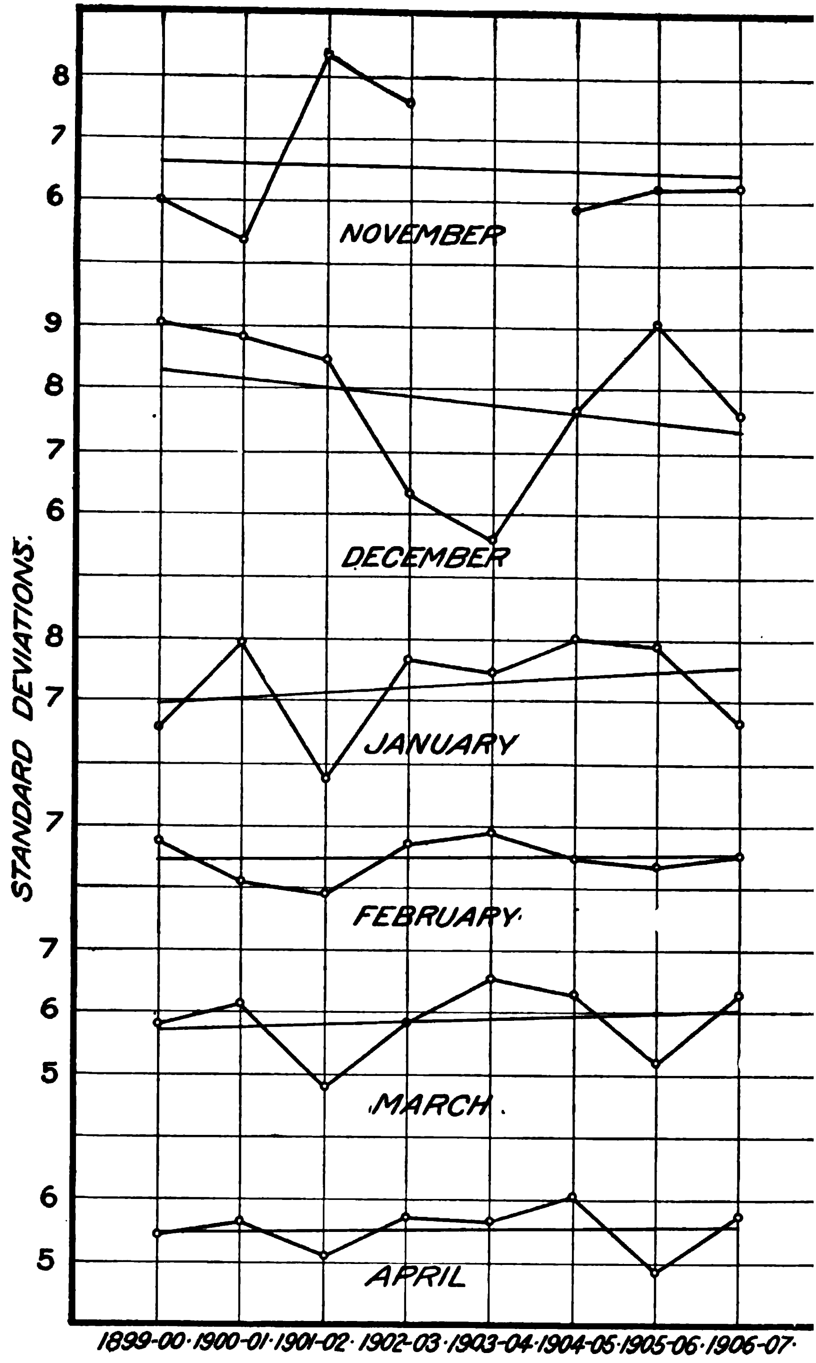

FIG. 9.—Diagram showing the trend of the observed absolute variability in monthly egg productio measured by the standard deviation in each of the months of November to April, inclusive, 1899-190

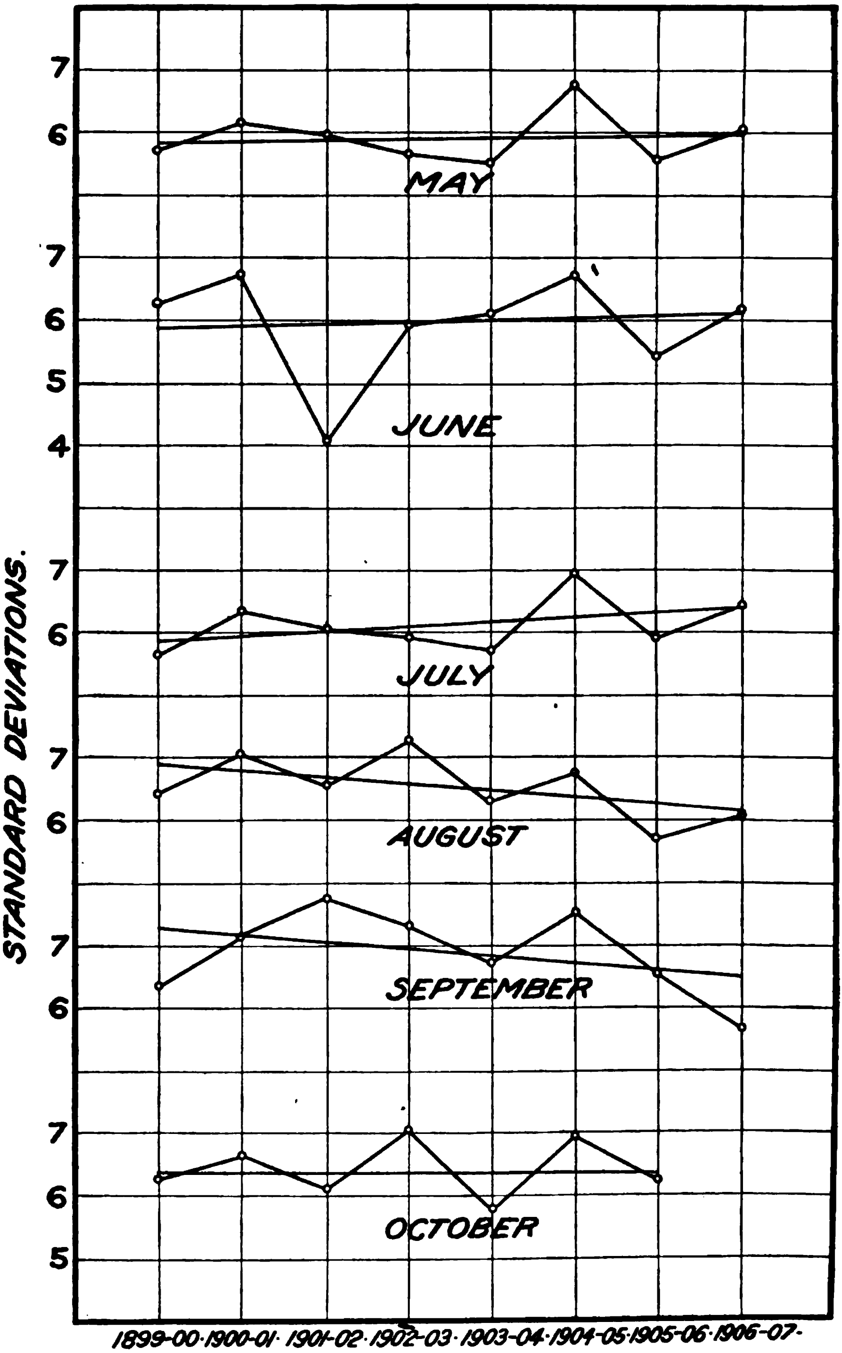

FIG. 10.—Diagram showing the trend of the observed absolute variability in monthly egg production as measured by the standard deviation in each of the months of May to October, inclusive, 1899-1907.

tically no effect either to decrease or to increase the absolute variability of the egg production of any of the single months.

2. The months showing the greatest decrease in the standard deviation are December and August. In both of these cases the decrease during the eight years is possibly significant statistically. Of the months showing an increase in the standard deviation the most marked are January and July. Comparison with figure 7 shows that January was the month in which the mean egg production showed the most pronounced drop during the period covered. We have here again an illustration of the rule brought out earlier in the paper that as mean egg production decreases the variability in this character tends to increase.

EFFECT ON RELATIVE VARIABILITY.

It has been seen throughout this study that the relative variability as given by the coefficient of variation is the more significant measure by which to arrive at a true conception of the actual existing degree of variability in egg production. Accordingly it is the more important to examine the trend of this constant with reference to the effect of selection. In making such an examination the same methods will be followed as in the case of the means and the standard deviations. The fundamental data are given in Table 4. These data are shown graphically in figures 11 and 12.

The equations to the straight lines in these figures are as follows, y denoting the coefficient of variation and x the number of years since the laying year 1898–99:

November	$y=143.09+0.260x$	May	$y=34.31+1.833x$
December	$y=92.18+2.899x$	June	$y=38.76+1.523x$
January	$y=39.03+8.958x$	July	$y=39.62+2.788x$
February	$y=49.63+2.599x$	August	$y=52.54+1.976x$
March	$y=37.39-.112x$	September	$y=61.08+3.874x$
April	$y=30.73+.740x$	October	$y=123.41+.153x$

From these diagrams (figs. 11, 12) the following points are to be noted:

1. With a single exception (March) the relative variability as measured by the coefficient of variation increased during the period in which selective breeding was practiced. The zigzag lines show that this increase was fairly steady and regular in nearly all cases, though it was very much more pronounced in some months than in others. In particular the variability of the January production increased very noticeably. This result indicates that the egg production of the single months follows the same rule as was shown to hold for the total annual production. So far as there was any change whatever in variability in monthly egg production during the period when selective breeding was practiced this change was not in the direction of

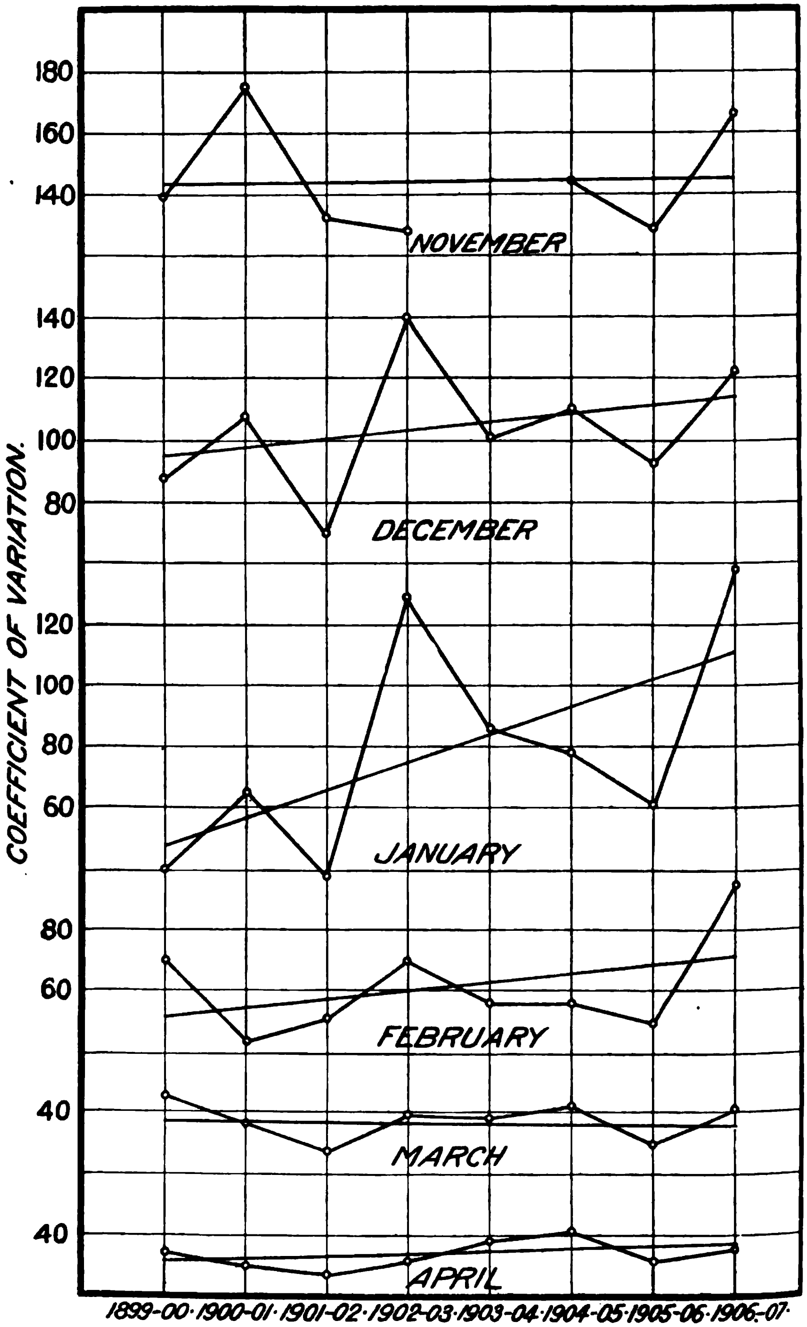

FIG. 11.—Diagram showing the course of the observed relative variability in egg production as measured by the coefficient of variation in each of the months of November to April, inclusive, 1899-1907.

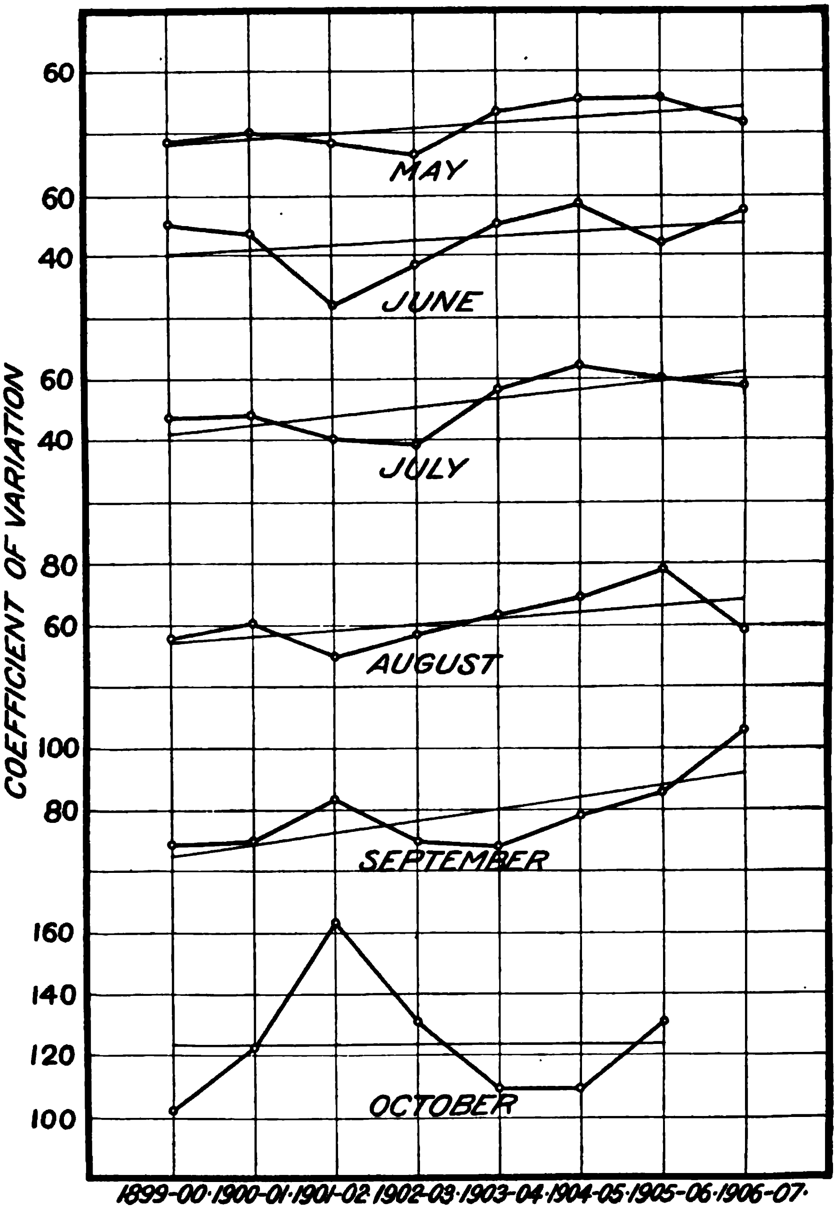

FIG. 12.—Diagram showing the course of the observed relative variability in egg production as measured by the coefficient of variation in each of the months of May to October, inclusive, 1899-1907.

a reduction, but, on the contrary, there was an actual increase in variability.

2. In the single month which forms the exception to the rule just stated, namely, March, the trend of the line of relative variability does not deviate sensibly from the horizontal. The explanation for this result is probably the same as that which was given for the behavior for the March mean production (see p. 102). In the months of March and April, which are the natural breeding season, laying is at its maximum and variability in production is at its minimum, and neither the mean production nor the variability in production is easily affected by selective breeding or by environmental influences. The egg production in these months is a fundamental and basic part of the reproductive cycle in the domestic fowl.

Putting all the results of this section together, it is seen that they are essentially the same as those which were reached in Part I from the study of total annual egg production. It might perhaps have been expected on a priori grounds that mass selection for increased annual production would at least have had a beneficial effect on winter egg production in the flocks. This, however, clearly was not the case. The general result was that the mean production for each month of the laying year either remained sensibly unchanged or showed a tendency to decrease during the period included in this experiment in selective breeding. At the same time the variability in monthly egg production, whether absolute or relative, either did not change at all or increased by a greater or less amount during the period through which the selection was practiced. In other words, it is seen that finer analysis of the total annual egg production returns does not tend in any way to change the conclusions drawn from the study of those returns, but, on the contrary, tends greatly to strengthen those conclusions. There can be no doubt whatever that in this experiment mass selection for increased egg production failed to attain its desired end.

INFLUENCE OF CERTAIN HOUSING CONDITIONS ON MONTHLY EGG PRODUCTION.

In Part I of this study (p. 58) there is described an experiment which was begun in the laying year 1904–5 and has been continued since that time to determine the influence on egg production of size of flock and amount of floor space per bird. Inasmuch as the general plan of this experiment has been fully described in the place cited, it will be unnecessary to repeat these details here. It need only be said that the birds were kept in flocks of 50, 100, and 150 each. The number of square feet of floor space per bird (4.8 square feet) was the same in the case of the 50-bird pens and the 100-bird pens, but in the 150-bird pens the floor space per bird (3.2 square feet) was about 1½ square feet less. From this arrangement of the flocks it is clear that data are furnished on two questions, namely, first, as to the effect on egg production of the number of birds kept together when floor space remains the same, and, second, as to the influence on egg production of the amount of floor space in itself.

In Part I the annual egg production of the flocks kept under these conditions during the years 1904–1907 was discussed. It was there shown that—

> When the laying hens were kept in flocks of 100 birds each, the average annual production per bird was distinctly and significantly lower than when they were kept in flocks of 50 birds each, though the number of square feet of floor space per bird was the same in the two cases and all other environmental conditions were made as nearly as possible identical. Laying birds kept in flocks of 150 birds each and with somewhat less floor space per bird than those kept in flocks of 50 and 100 birds each have in every case an average annual egg production significantly smaller than that of the birds kept in small flocks.

In discussing these results it was pointed out that caution must be shown in drawing practical conclusions from them, since they were based on annual returns only. In this section we shall deal with the effect of these housing conditions on monthly egg production. We may consider first the mean or average monthly production for each month in the period from November, 1904, to January, 1908.

INFLUENCE OF HOUSING CONDITIONS ON AVERAGE MONTHLY PRODUCTION.

The data for discussing the influence of housing conditions on mean production are given in Table 6. This table gives the results of a comparison of 50-bird with 100-bird pens, of 50-bird with 150-bird pens, and of 100-bird with 150-bird pens. The fundamental figures on which this table is based are the mean monthly productions and their probable errors given in Table 1 (pp. 86, 87). The best way in which to make a comparison between these different pens in the different years appears to be to find the differences between the mean monthly production of the flocks kept in the different sized pens for each month. In order that these differences may be expressed always in a uniform manner, the table is arranged in such a way as to show in its three columns, first, the amount by which the mean production of flocks kept in 50-bird pens exceeds that of flocks kept in 100-bird pens for each month of the laying year; second, the amount by which the mean production of flocks kept in 50-bird pens exceeds that of flocks kept in 150-bird pens; and, finally, the amount by which the mean production of flocks kept in 100-bird pens exceeds that of flocks kept in 150-bird pens. Under this arrangement, when the first designated flock of a pair is in excess the sign of the difference is plus, and when the second designated flock of a pair is in excess the sign is minus. To take an example: It appears from the second line of Table 6 that in December, 1904, the birds kept in 150-bird pens had a mean production 3.54 eggs higher than the mean production of the birds kept in 50-bird pens in the same month and year. The probable errors of the differences in Table 6 are calculated in the usual way.

It will be noted that data for only eight months of the laying year 1907–8 are given. The reason for this is that owing to the necessity for a thorough overhauling of the poultry plant in the summer of 1908, trap-nest records had to be stopped on July 1 of that year, and no returns for that year were made after that date.

Table 6.—*Differences in mean monthly egg production between flocks of different sizes.*

Year and month.	Difference in egg laying between—		
	50 and 100 bird pens.	50 and 150 bird pens.	100 and 150 bird pens.
1904–5—November	−1.81±.58	−1.00±.45	+0.81±.68
December	−5.04±.60	−3.54±.55	+1.50±.69
January	−1.08±.61	− .69±.56	+ .39±.68
February	+2.20±.50	+4.37±.47	+2.17±.58
March	+5.75±.48	+5.96±.47	+ .21±.59
April	− .17±.48	+2.35±.43	+2.52±.55
May	− .57±.49	+1.83±.49	+2.40±.58
June	− .75±.53	+2.37±.49	+3.12±.62
July	− .77±.56	+1.06±.51	+1.83±.67
August	− .13±.56	+2.52±.47	+2.65±.62
September	+ .20±.63	+3.33±.51	+3.13±.69
October	+1.67±.57	+1.57±.47	− .10±.60
1905–6—November	+ .91±.47	+2.62±.41	+1.71±.39
December	− .05±.64	+ .26±.60	+ .31±.58
January	+ .56±.54	+1.39±.51	+ .83±.51
February	+1.07±.44	+2.82±.40	+1.75±.43
March	+ .96±.39	+1.27±.33	+ .31±.35
April	+1.40±.35	+1.28±.30	− .12±.33
May	+ .68±.40	+ .75±.35	+ .07±.37
June	+ .71±.38	+1.82±.33	+1.11±.38
July	+ .65±.41	+1.40±.37	+ .75±.40
August	+2.32±.39	+2.68±.37	+ .36±.37
September	+2.31±.47	+2.94±.43	+ .63±.43
October	+1.14±.45	+1.51±.41	+ .37±.39
1906–7—November	− .04±.39	−1.03±.38	− .99±.41
December	−1.46±.51	−3.14±.46	−1.68±.50
January	+1.38±.47	+1.03±.43	− .35±.43
February	+5.31±.44	+3.67±.43	−1.64±.41
March	+3.67±.43	+3.07±.40	− .69±.40
April	+ .71±.40	+1.91±.37	+1.20±.37
May	− .80±.43	+1.50±.39	+2.30±.38
June	−1.98±.42	+ .51±.40	+2.49±.40
July	+ .79±.44	+2.24±.40	+1.45±.42
August	+ .03±.43	+2.43±.37	+2.40±.41
September	−3.47±.40	− .15±.33	+3.32±.39
1907–8—November	+ .55±.27	+ .70±.51	+ .15±.49
December	+ .99±.74	+2.34±.63	+1.35±.60
January	+ .32±.74	+2.36±.65	+2.04±.69
February	−4.08±.69	−3.88±.60	+ .20±.66
March	+2.21±.73	+1.80±.62	− .41±.68
April	+2.25±.76	+ .46±.66	−1.79±.67
May	+2.88±.72	+2.51±.63	− .37±.65
June	+4.34±.63	+2.69±.57	−1.65±.59

The first thing which is apparent from an examination of this table is that while one certain size of flock and pen may always show a greater mean annual production than the others, this superiority is not uniformly present in each month of the laying year. On the contrary, it is clearly evident from the table that sometimes one size of flock is in excess in a particular month, sometimes another. This, together with the fact that a large amount of material is included in the table, make it as it stands rather confusing and difficult to draw any conclusions from. In order to get at the essential facts regarding the influence of housing conditions on mean monthly egg production, it is desirable to get the data in diagrammatic form. This has been done with the results shown in figures 13, 14, and 15. These figures show for each month of the laying year the average excess of the first designated flock of the pair over the second in mean egg production. The averages are taken for the four years covered in the case of the months of the laying year before July and for three years in the months after July. In calculating these averages the signs of the separate entries are, of course, observed. In platting the figures, there has been placed on either side of the zero line what may be called a probable error line. This line is at a distance from the zero line equal to the mean of the probable errors contained in the column on which the diagram is based. October is not included in these diagrams, because we have data on this month for but two years.

From these diagrams and the data on which they are based, the following points are to be noted:

1. The flocks kept in 50-bird pens do not, in general, show an excess in mean production over those kept in 100-bird and 150-bird pens in the first three winter months—November, December, and January. In those months the birds in the 100-bird or in the 150-bird pens show average productions either higher or at least sensibly equal to those of the flocks in the 50-bird pens. In other words, the figures obtained from the four years' experiment seem to indicate clearly that winter egg production is not adversely affected by keeping the birds in large flocks, and even by crowding them so that each bird has only a little over 3 square feet of floor space.

2. The greatest excess in mean production of flocks kept in 50-bird pens over those kept in either 100 or 150 bird pens is in the month of March. In this month the smaller flocks are very markedly superior to the larger ones in egg production.

3. Aside from the maximum excess in March of the smaller flocks over the larger, there is a secondary and smaller excess to be observed in the month of August. In this month the 50-bird pens show a decided superiority over the larger flocks. This would appear to indicate that, as would be expected, overcrowding shows its bad effect chiefly in the extremely hot weather of midsummer.

4. In all the months after and including February the excess of the 50-bird pens over the 150-bird pens in mean production is very marked. In the months after March this is probably to be explained as a result of the depressing effect of increasingly warmer weather on birds kept in large and crowded flocks. The reason for the excess in the months of February and March is not apparent.

5. Up until May there is no significant difference in mean monthly egg production between flocks kept in 100 and 150 bird pens. The line fluctuates up and down, but does not extend significantly above the probable error lines. After this month (that is, from May to September, inclusive) the 100-bird pens show marked and increasing superiority in mean monthly egg production over the 150-bird pens. In this we again see the bad effect on egg production of crowding in hot weather.

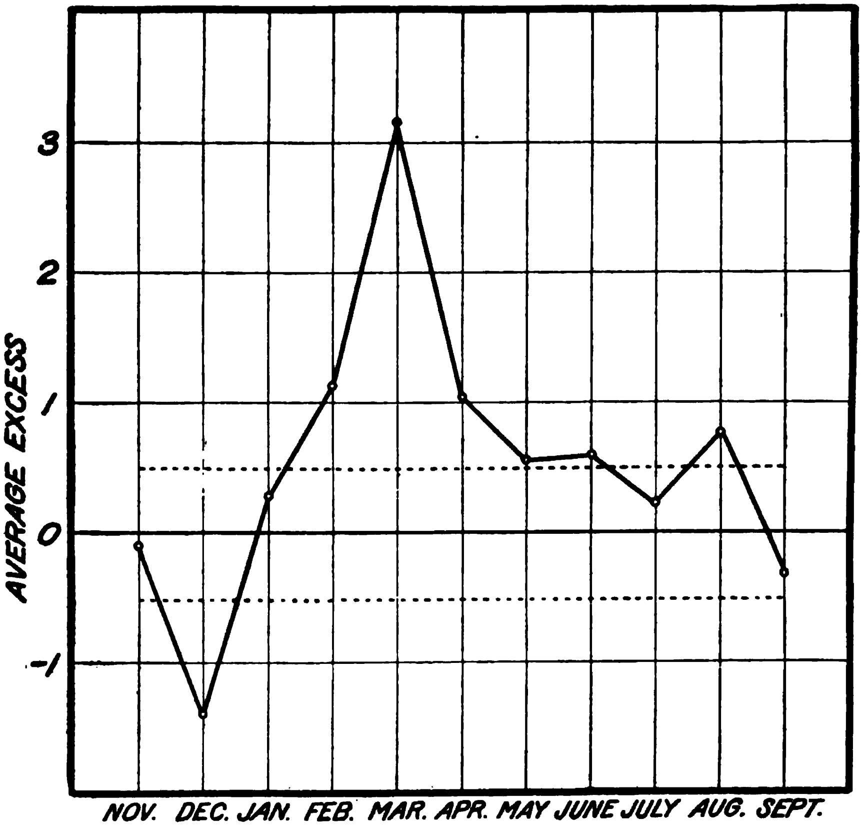

FIG. 13.—Diagram showing the average excess in mean egg production of flocks kept in 50-bird pens over flocks kept in 100-bird pens for the first eleven months of the laying year, November to September.

6. Summarizing, we may say that, so far as winter egg production is concerned, the present statistics show no bad effects of keeping birds in large and crowded flocks (up to the limits included in the present study). On the other hand, overcrowding tends distinctly to lower summer egg production. It is chiefly as a result of this effect upon summer production that the mean annual production is lower in the large flocks, as shown in Part I, pages 58–61.

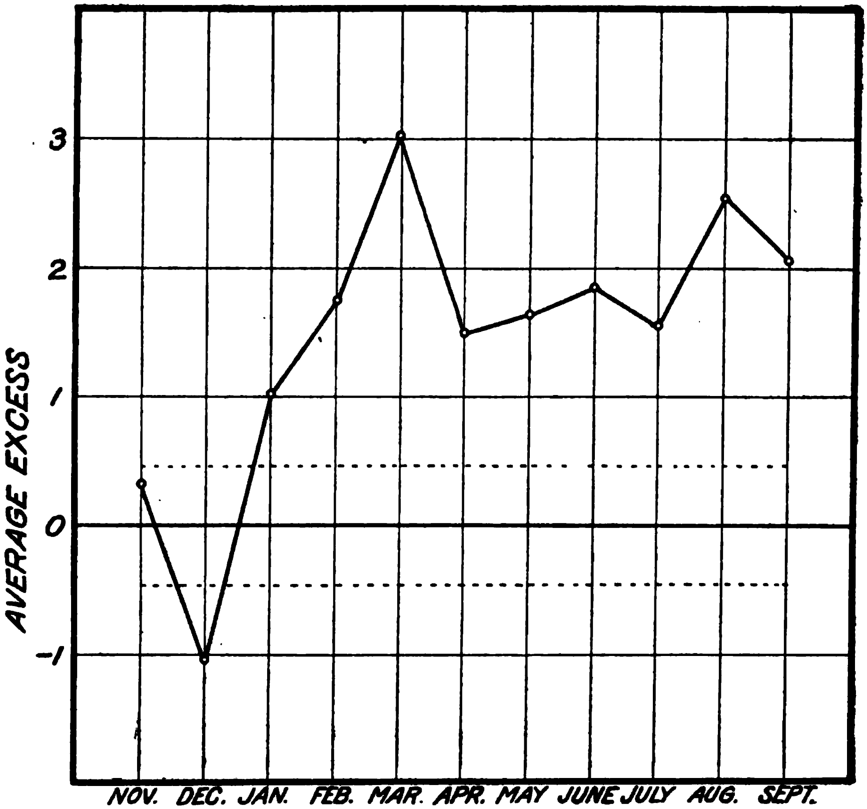

FIG. 14.—Diagram showing the average excess in mean egg production of flocks kept in 50-bird pens over flocks kept in 150-bird pens for the first eleven months of the laying year, November to September.

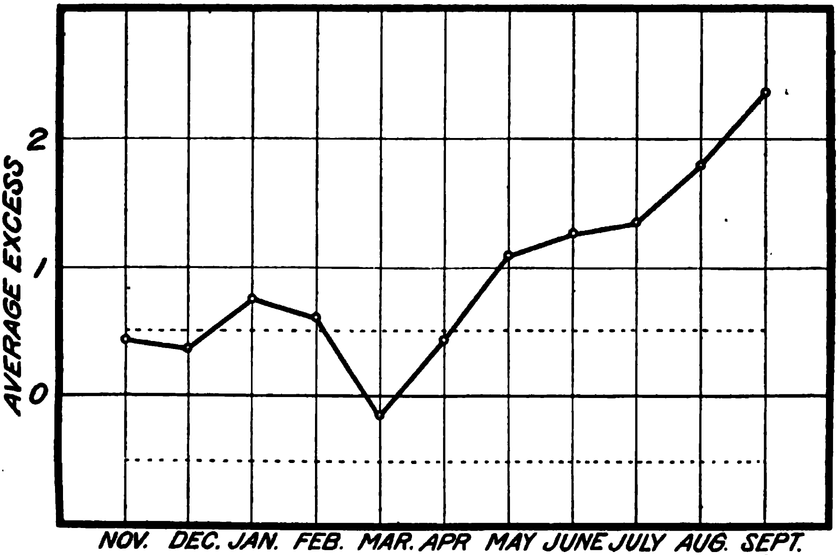

FIG. 15.—Diagram showing the average excess in mean egg production of flocks kept in 100-bird pens over flocks kept in 150-bird pens for the first eleven months of the laying year, November to September,

INFLUENCE OF FLOCK SIZE ON VARIABILITY IN EGG PRODUCTION.

We may turn next to the subject of the effect of flock size upon variability in egg production in the several months of the year. In connection with this question it will be necessary to discuss only the coefficients of variation for reasons already set forth (p. 94, and Pt. I, p. 44). The coefficient of variation gives us a measure of the relative or percentage variability. Such data may be used for purposes of comparison.

As in the case of the mean monthly production (p. 113), the most satisfactory way of dealing with the data is to put them in the form of a difference table for the coefficients of variation. This is done in Table 7, which is constructed in exactly the same way as was Table 6. The first column gives the difference in variability between 50 and 100 bird pens, the second column between 50 and 150 bird pens, and the last column between 100 and 150 bird pens. A difference is noted as plus when the first flock size of a designated pair is the more variable and as minus when the second flock size is the more variable.

TABLE 7.—*Differences in relative variability in egg production, between flocks of different sizes, as measured by the coefficient of variation.*

Year and month.	Difference between—		
	50 and 100 bird pens.	50 and 150 bird pens.	100 and 150 bird pens.
1904-5—November	+40.35±15.54	+ 32.71±15.59	− 7.64±[illegible]
December	+65.58± 9.53	+ 46.55±10.01	−19.03±[illegible]
January	+18.86± 5.73	+ 10.22± 5.65	− 8.64±[illegible]
February	− 5.94± 3.76	− 20.29± 5.52	−26.23±[illegible]
March	−16.21± 3.09	− 27.17± 3.29	−10.96±[illegible]
April	+ .34± 2.49	− 9.88± 2.67	−10.22±[illegible]
May	+ 9.59± 2.86	− 10.87± 3.64	−20.46±[illegible]
June	+ 2.87± 3.45	− 21.24± 4.42	−24.11±[illegible]
July	− 1.09± 4.60	− 19.44± 5.31	−18.35±[illegible]
August	− .53± 4.96	− 19.06± 5.69	−18.53±[illegible]
September	− 3.24± 6.04	− 24.83± 7.08	−21.59±[illegible]
October	−20.15±14.76	− 8.49± 9.90	+11.66±[illegible]
1905-6—November	−11.66±11.00	− 40.37±12.26	−28.71±[illegible]
December	+ 2.85± 9.86	− 4.04± 9.65	− 6.89±[illegible]
January	− 3.71± 3.57	− 13.90± 3.62	−10.19±[illegible]
February	− 9.70± 2.63	− 19.36± 2.70	− 9.66±[illegible]
March	− 5.00± 1.69	− .59± 3.84	+ 4.41±[illegible]
April	− 6.21± 1.71	− 4.02± 1.47	+ 2.19±[illegible]
May	− 7.43± 3.10	− 6.68± 2.74	+ .75±[illegible]
June	−10.56± 2.43	− 12.40± 2.21	− 1.84±[illegible]
July	−13.22± 3.71	− 17.50± 3.47	− 4.28±[illegible]
August	−19.70± 5.03	− 29.14± 4.93	− 9.44±[illegible]
September	−22.31± 6.08	− 29.70± 5.77	− 7.39±[illegible]
October	−19.32±12.59	− 26.82±11.79	− 7.50±[illegible]
1906-7—November	−28.19±22.27	− 6.10±17.46	+22.09±[illegible]
December	+15.80±14.73	+ 41.93±12.50	+26.13±[illegible]
January	−33.49±14.99	− 25.41±12.31	+ 8.08±[illegible]
February	− 4.89± 8.49	− 38.55± 5.79	+16.34±[illegible]
March	−10.26± 2.25	− 10.97± 2.00	− .71±[illegible]
April	− .91± 1.86	− 5.57± 1.82	− 4.71±[illegible]
May	+ 3.90± 2.37	− 2.84± 2.36	− 6.74±[illegible]
June	+ 8.65± 3.06	− 6.37± 3.30	−15.02±[illegible]
July	− 6.40± 3.30	− 16.19± 3.34	− 9.79±[illegible]
August	−10.16± 3.56	− 21.17± 3.64	−11.01±[illegible]
September	+26.65± 7.48	− 12.89± 9.11	−39.54±[illegible]
1907-8—November	−51.47±56.41	−112.80±65.85	−61.33±[illegible]
December	−23.64±29.39	− 58.49±32.12	−34.85±[illegible]
January	−16.30±14.45	− 52.31±17.28	−36.01±[illegible]
February	+48.09±14.79	+ 51.29±14.24	+ 3.20±[illegible]
March	−12.65± 3.89	− 4.18± 3.03	+ 8.47±[illegible]
April	− 7.93± 3.92	+ 2.15± 3.07	+10.08±[illegible]
May	−11.67± 4.08	− 6.19± 3.32	+ 5.48±[illegible]
June	−19.98± 4.77	− 11.76± 3.60	+ 8.22±[illegible]

Just as in the case of the means, the mass of data presented in the table is so great as to be confusing. It is difficult to draw any conclusions from the detailed constants. As an aid in the interpretation of the table we may again resort to the use of graphical methods. Figures 16, 17, and 18 are diagrams showing the average excess in relative variability as measured by the coefficient of variation of, respectively, 50-bird pens over 100-bird pens, 50-bird pens over 150-bird pens, and 100-bird pens over 150-bird pens. These diagrams are constructed on exactly the same plan as figures 13, 14, and 15. If in the description of the plan of those diagrams on page 115 the words "coefficient of variation" be substituted for "mean" whenever it occurs, that account will describe the diagrams here, and need not be repeated.

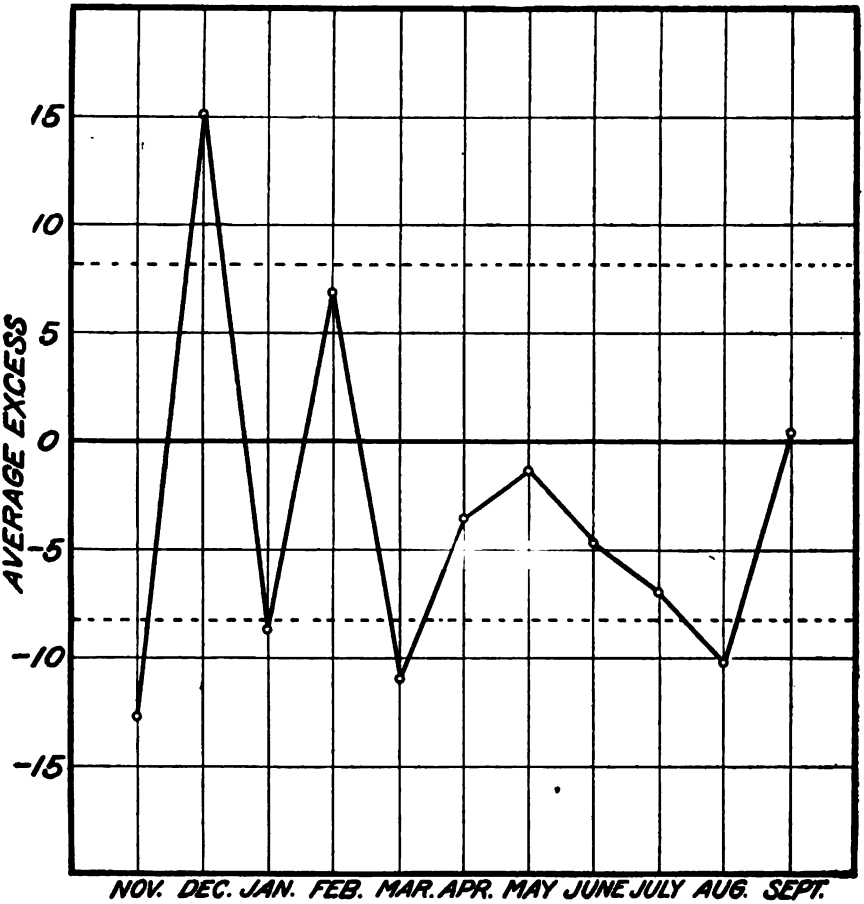

FIG. 16.—Diagram showing the average excess in relative variability, as measured by the coefficient of variation, of flocks of 50 birds over flocks of 100 birds for the first eleven months of the laying year, November to September.

From these diagrams and the data on which they are based we note the following points:

1. The excess in relative variability of egg production of the larger flocks (100 and 150 birds) over the smaller (50 and 100 birds) is on the whole fairly evenly distributed over the whole year. In only one case (December, 50 and 100 bird pens) do we find any considerable + excess, denoting for that month a greater variability of the smaller

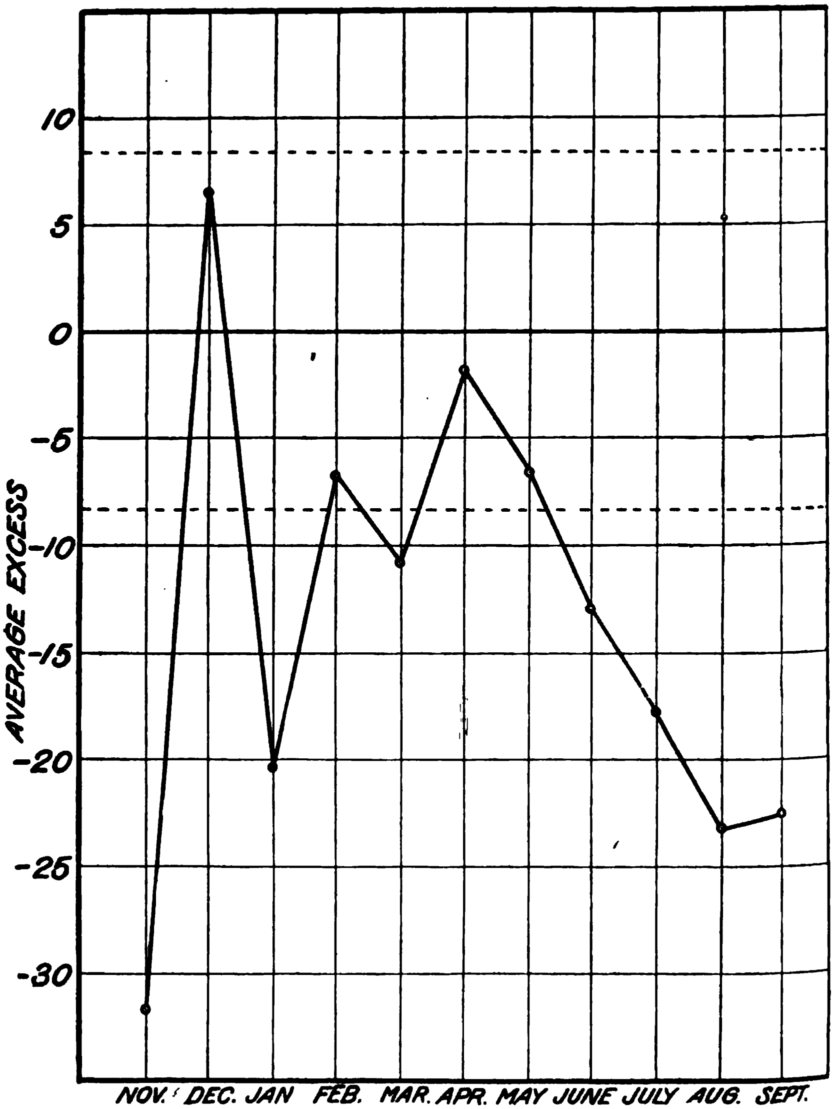

FIG. 17.—Diagram showing the average excess in relative variability, as measured by the coefficient of variation, of flocks of 50 birds over flocks of 150 birds for the first eleven months of the laying year, November to September.

flock. In this case, further, the average result very largely depends upon the very great difference observed in the single year 1904–5, which in turn results from the very high relative and absolute variability shown by the 50-bird flocks in their December production of that year.

2. In the period comprised within the months February to July, inclusive, there is no significant difference in relative variability between any of the flocks. In other words, it appears that during that period of the year in which there is the heaviest production such environmental differences as are implied in the different flock sizes in this experiment do not appreciably affect the relative variability of production.

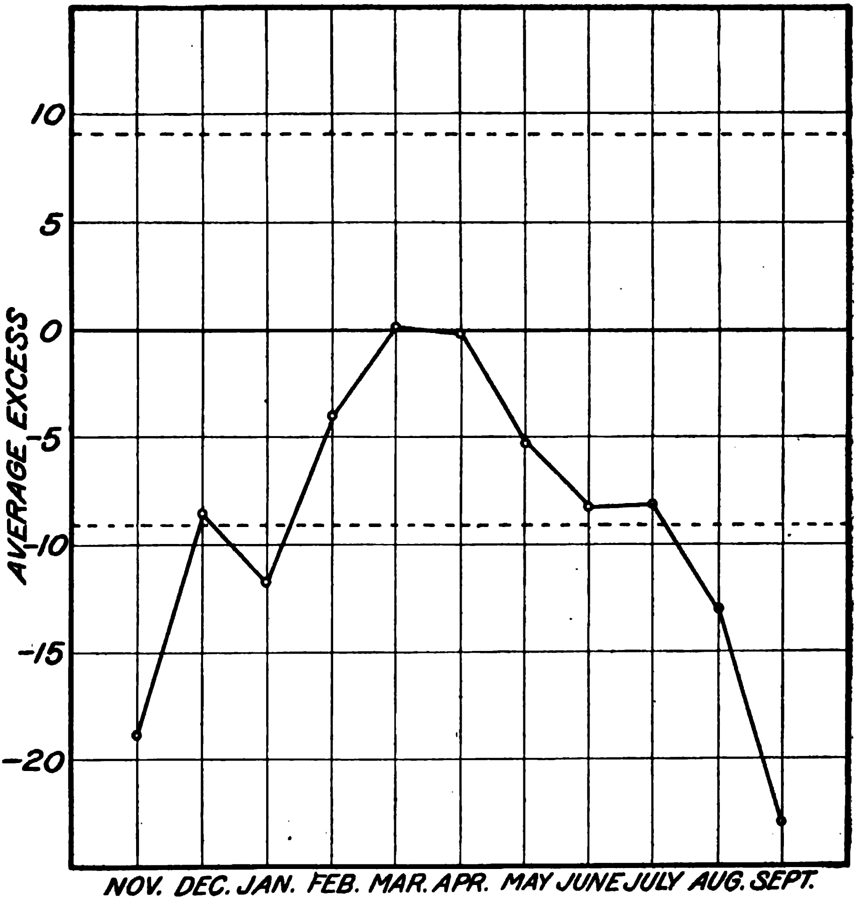

FIG. 18.—Diagram showing the average excess in relative variability, as measured by the coefficient of variation, of flocks of 100 birds over flocks of 150 birds, for the first eleven months of the laying year, November to September.

3. The greatest effect of flock-size and floor-space factors on relative variability of production is to be seen in the months of

November and September—at the beginning and the end of the laying year.

In the discussion of the influence of floor space and flock size on mean annual production in Part I (p. 63) it was pointed out that caution must be exercised in drawing practical conclusions from the annual data. The reason for such caution is apparent from the facts set forth in the present section. It has been shown that while it is true that the average annual production of large and relatively crowded flocks is not so great as that of smaller flocks with or without more floor space per bird, yet the difference is, for practical purposes, almost entirely in the economically unimportant summer egg production. Winter egg production is, speaking generally, in no wise adversely affected by keeping the birds in 100 and 150 bird flocks and allowing as little as 3.2 square feet of floor space per bird. The most probable reason for such a result as this would appear to lie in temperature relations. The large, crowded flocks presumably get a greater benefit from their animal heat in the cold winter months, particularly at night on the roosts. This means a smaller strain on the metabolic mechanism solely for the purpose of maintaining body temperature. In the hot summer months the same factors operate in the opposite way. That hens suffer greatly in very hot weather everyone who has observed them knows. That a crowded condition, particularly on the roosts, is likely to increase the discomfort from heat seems very probable.

All of these considerations have led the writers to the tentative opinion that the number of cubic feet of space in a house is a much more important and significant factor in the poultry-housing problem than is the number of square feet of floor space. And particularly the number of cubic feet per bird in the so-called "roosting closet" of houses of the curtain-front type would seem to be a significant factor, the possible influence of which on egg production and the general well-being of birds ought to be subjected to more thorough and careful experimental study than has ever been given to it so far as the writers are aware. It seems possible that along this line may be found the explanation of the good results obtained by Robinson[a] with his "low type" of house. Theoretically it would seem probable that there is some general relation—not absolutely fixed, but varying within narrow limits—between square feet of floor space per bird, cubic feet of house space per bird, and the well-being and productiveness of hens. The practical problem is to find out what this relation is.

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[a] Robinson, J. H. The Height of the Poultry House. Farm Poultry. Vol. XIX, p. 342, 1908.

THE FREQUENCY DISTRIBUTION OF VARIATION IN MONTHLY EGG PRODUCTION.

In Part I (pp. 30–38) of this study the frequency distributions for variation in annual production were discussed analytically, and it was shown that in general variation in egg production followed the same laws as hold for fluctuating variation in other characters. But these annual production curves present only the gross facts of variation in egg production. They present rather than solve a problem. It is necessary to analyze these annual curves into their components in order to arrive at an idea of the factors involved in their genesis. That is to say, while we know that all such curves showing the distribution of fluctuating variations arise through the operation of an indefinite number of small "chance" or "statistical" causes, there is involved in every frequency curve a specific and particular biological problem. The problem is this: What are the immediate biological factors which result in the genesis of the particular form of frequency curve shown by the given material rather than some other form? It was shown in Part I of this study that the curves for variation in annual production had certain definite characters peculiar to themselves. Thus there appeared to be a general tendency for such curves to have an unduly high frequency at the low-production end of the curve. Their skewness was always in the same direction. Now, how does it come about (i. e., what are the proximate causes) that these egg-production curves show these particular characteristics rather than some others? This is the problem presented by gross frequency curves. The first step toward answering it must be made by further analyzing these curves. Final analysis in terms of individuals must always be the goal aimed at.

It is evident that a study of the distribution of variation in monthly egg production may well serve as a beginning of the analysis of annual egg-production curves. It will be understood, of course, that this is in no sense an analysis in terms of individual variants, but rather in terms of a smaller time unit. It seems wise to begin this study of the monthly distributions of variation in egg production with a general graphical appreciation of their characteristics. Following this the detailed mathematical treatment will be undertaken. For the graphical treatment all available data have been used. The monthly frequency distributions so formed are given in Table 8. The absolute frequencies in this table are the totals of the fundamental Tables I to XII of Appendix II. From these absolute frequencies the percentage frequencies used in the diagrams were calculated. The manner in which the table is to be read may be illustrated with an example: The first entry in the table means that of the 2,153 hens for which we have November production records 1,189, or 55.22 per cent, laid no eggs in that month.

TABLE 8.—*Absolute and percentage frequency distributions for the egg production in each month of the laying year, based on the records of the years 1899–1900 to 1906–7, inclusive.*

Eggs laid.	November.		December.		January.		February.	
	Absolute frequency.	Percentage frequency.	Absolute frequency.	Percentage frequency.	Absolute frequency.	Percentage frequency.	Absolute frequency.	Percentage frequency.
0	1,189	55.22	906	37.68	654	27.17	322	13.38
1	137	6.36	123	5.11	107	4.45	86	3.51
2	47	2.18	67	2.78	71	2.95	68	2.83
3	37	1.72	51	2.12	65	2.70	65	2.70
4	26	1.21	63	2.62	59	2.45	68	2.83
5	36	1.67	57	2.37	48	1.99	84	3.49
6	37	1.72	49	2.04	64	2.66	69	2.87
7	32	1.49	53	2.20	49	2.04	90	3.74
8	32	1.49	59	2.45	55	2.29	78	3.24
9	41	1.90	58	2.41	60	2.49	66	2.74
10	39	1.81	67	2.78	70	2.91	93	3.86
11	49	2.28	52	2.16	52	2.16	73	3.03
12	36	1.67	54	2.24	62	2.58	94	3.91
13	61	2.83	55	2.29	72	2.99	75	3.12
14	47	2.18	59	2.45	72	2.99	116	4.82
15	77	3.58	45	1.87	85	3.53	123	5.11
16	36	1.67	72	2.99	89	3.70	158	6.56
17	43	2.00	60	2.49	91	3.78	135	5.61
18	39	1.81	87	3.61	94	3.91	162	6.73
19	41	1.90	80	3.32	97	4.03	126	5.23
20	23	1.07	71	2.95	94	3.91	119	4.94
21	24	1.11	56	2.33	108	4.49	72	2.99
22	13	.60	56	2.33	90	3.74	41	1.70
23	5	.23	49	2.04	49	2.04	14	.58
24	6	.28	35	1.45	29	1.20	8	.33
25	...	...	15	.62	13	.54	1	.04
26	...	...	4	.17	5	.21	1	.04
27	...	...	3	.12	3	.12	...	...
28	...	...	1	.04	...	...	...	...
29	...	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...	...
31	...	...	...	...	...	...	...	...
Total	2,153	100.00	2,407	100.03	2,407	100.02	2,407	99.99

Eggs laid.	March.		April.		May.		June.	
	Absolute frequency.	Percentage frequency.	Absolute frequency.	Percentage frequency.	Absolute frequency.	Percentage frequency.	Absolute frequency.	Percentage frequency.
0	68	2.83	55	2.29	118	4.90	193	8.02
1	24	1.00	29	1.20	50	2.08	44	1.83
2	13	.54	16	.66	33	1.37	30	1.25
3	19	.79	19	.79	23	.96	27	1.12
4	26	1.08	18	.75	42	1.74	34	1.41
5	29	1.20	23	.96	47	1.95	31	1.29
6	25	1.04	25	1.04	55	2.29	45	1.87
7	44	1.83	33	1.37	58	2.41	54	2.24
8	64	2.66	28	1.16	100	4.15	100	4.15
9	69	2.87	58	2.41	91	3.78	108	4.49
10	63	2.62	76	3.16	126	5.23	129	5.36
11	94	3.91	79	3.28	170	7.06	172	7.15
12	109	4.53	119	4.94	149	6.19	181	7.52
13	98	4.07	125	5.19	158	6.56	151	6.27
14	101	4.20	150	6.23	156	6.48	161	6.69
15	103	4.28	168	6.98	150	6.23	145	6.02
16	132	5.48	162	6.73	121	5.03	151	6.27
17	150	6.23	186	7.73	130	5.40	116	4.82
18	143	5.94	185	7.69	111	4.61	97	4.03
19	178	7.40	171	7.10	108	4.49	97	4.03
20	171	7.10	184	7.64	102	4.24	107	4.45
21	158	6.56	164	6.81	93	3.86	90	3.74
22	178	7.40	124	5.15	78	3.24	60	2.49
23	147	6.11	95	3.95	60	2.49	44	1.83
24	111	4.61	63	2.62	33	1.37	16	.66
25	54	2.24	29	1.20	25	1.04	11	.46
26	22	.91	15	.62	11	.46	8	.33
27	8	.33	5	.21	5	.21	2	.08
28	5	.21	3	.12	2	.08	3	.12
29	1	.04	...	...	1	.04	...	...
30	0	...	...	...	0	...	...	...
31	0	...	...	...	1	.04	...	...
Total	2,407	100.01	2,407	99.98	2,407	99.98	2.407	99.99

TABLE 8.—*Absolute and percentage frequency distributions for the egg production in each month of laying year, based on records of years 1899–1900 to 1906–7, inclusive*—Cont'd.

Eggs laid.	July.		August.		September.		October.	
	Absolute frequency.	Percentage frequency.	Absolute frequency.	Percentage frequency.	Absolute frequency.	Percentage frequency.	Absolute frequency.	Percentage frequency.
0	297	12.34	345	14.33	554	23.02	773	44.07
1	48	1.99	109	4.53	147	6.11	114	6.50
2	35	1.45	53	2.20	86	3.57	52	2.96
3	27	1.12	55	2.29	64	2.66	38	2.17
4	42	1.74	53	2.20	69	2.87	41	2.34
5	55	2.29	68	2.83	89	3.70	44	2.51
6	65	2.70	77	3.20	91	3.78	38	2.17
7	86	3.57	82	3.41	95	3.95	41	2.34
8	110	4.57	103	4.28	100	4.15	45	2.57
9	125	5.19	105	4.36	89	3.70	56	3.19
10	157	6.52	151	6.27	93	3.86	40	2.28
11	168	6.98	169	7.02	100	4.15	61	3.48
12	164	6.81	151	6.27	99	4.11	55	3.13
13	167	6.94	142	5.90	105	4.36	52	2.96
14	144	5.98	130	5.40	86	3.57	54	3.08
15	119	4.94	123	5.11	79	3.28	57	3.24
16	109	4.53	94	3.91	71	2.95	56	3.19
17	95	3.95	84	3.49	92	3.82	43	2.45
18	81	3.36	75	3.12	61	2.53	38	2.17
19	79	3.28	67	2.78	67	2.78	19	1.08
20	60	2.49	53	2.20	51	2.12	15	.86
21	59	2.45	40	1.66	55	2.29	9	.51
22	36	1.50	21	.87	34	1.41	3	.17
23	35	1.45	35	1.45	17	.71	4	.22
24	20	.83	11	.46	6	.25	4	.22
25	11	.46	7	.29	4	.17	1	.06
26	6	.25	3	.12	3	.12	0	....
27	4	.17	0	....	....	....	1	.06
28	1	.04	1	.04	....	....	....	....
29	0	....	....	....	....	....	....	....
30	0	....	....	....	....	....	....	....
31	2	.08	....	....	....	....	....	....
Total	2,407	99.97	2,407	99.99	2,407	99.99	1,754	99.98

The data of the foregoing table are given graphically in figures 19 to 24, inclusive. These figures are the graphs of the percentage distributions, the percentage rather than the absolute figures being used in order to make all the diagrams directly comparable one with another. The area of each is the same. To economize space the distributions for two successive months are put together in the same diagram. In all these diagrams the ordinates denote the percentage frequency of birds each laying the number of eggs designated by the abscissa.

The first point which is at once noticed on examining these frequency polygons is that we are clearly not dealing here with simple frequency distributions such as are usually found in variation studies in which the variants are distributed about a single center or mode.[a] The nearest approach among these polygons to this ordinary unimodal type of frequency curve is found in the distributions for March and April, and in particular that for April. But even in this case

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[a] The "mode" of a frequency curve is that particular value of the varying character (here "eggs produced per month") which is present in the largest number of the varying individuals making up the population. A modal egg production of 15 eggs for November would mean that more birds produced just 15 eggs in that month than produced any other one particular number of eggs, either greater or less than 15. For a further discussion of the significance of this constant see Part I, page 27. A curve which shows a single "peak" or maximum ordinate is said to be unimodal; one which has two, to be bimodal, and one which has more than two to be multimodal.

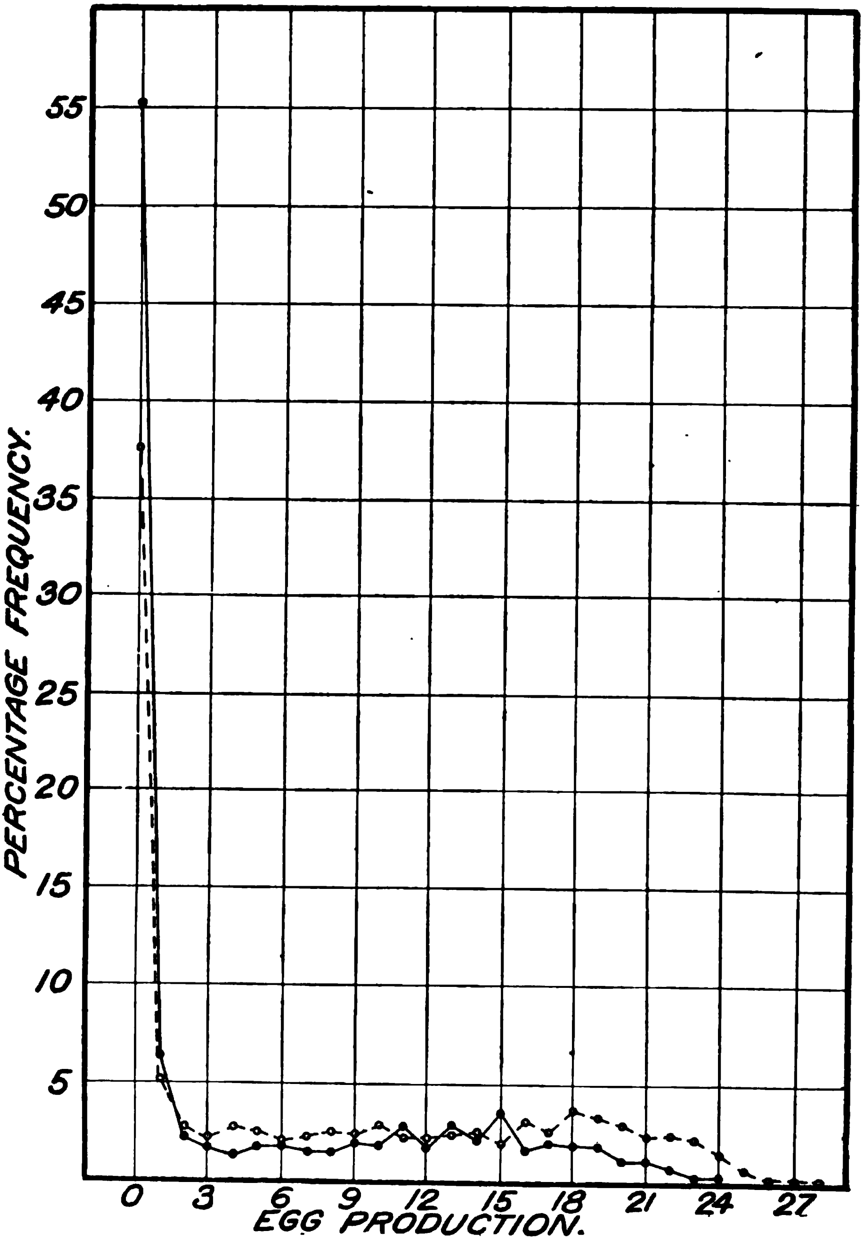

FIG. 19.—Frequency polygon of variation in November and December egg production.

the distribution clearly differs from the usual frequency curve. All of these polygons are distinctly bimodal in some degree. Each one shows one distinct mode at zero egg production. The fact that every single one of the monthly frequency distributions clearly and definitely shows this bimodal condition indicates that we are dealing with a real phenomenon of variation. In fact, as will presently appear, we apparently have to do in these cases with a definite and hitherto unrecognized type of frequency distribution. Simple bimodal distributions have, of course, been known since the beginning of the statistical study of variation. Such distributions, however, have practically only been noted hitherto for cases of dimorphism, where one deals with so-called "high" and "low" forms of the organism. Such distributions have, for example, among animal forms, been described by Bateson[a] for *Forficula* and for the rhinoceros beetle (*Xylotrupes gideon*), and by Graber[b] for *Blissus* and others.

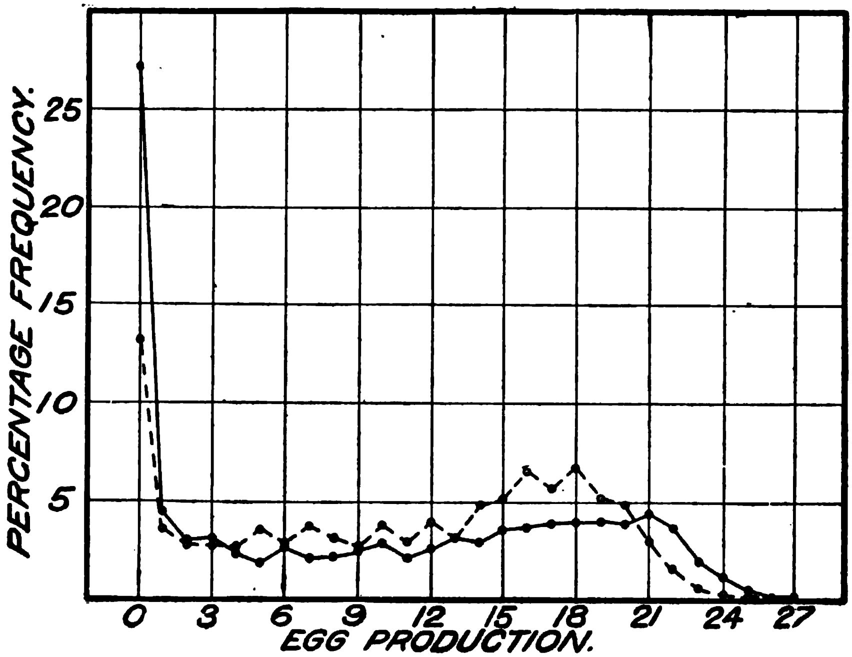

FIG. 20.—Frequency polygon of variation in January and February egg production.

Apart from these cases of dimorphism, variation leading to frequency distributions of anything other than the common unimodal type occurs very rarely. Even with all the work which has been done in recent years in the biometrical study of fluctuating variation there have been extremely few instances brought to light which do not conform to the unimodal type of distribution. Besides dimorphism already noted, practically the only instances of multimodal distributions which have been brought forward are those for variation in the number of ray flowers in certain of the Compositæ.[a] In these cases there is some evidence of a tendency toward the occurrence of definite peaks or modes on the Fibonacci numbers. It is the fact, however, that the statistical significance of these observational modes has never yet been adequately settled.

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[a] Bateson, W. Materials for the Study of Variation. London, 1894, pp. 36–42.

[b] Graber, J. F. Dimorphism in *Blissus leucopterus*. Biological Bulletin, vol. 5, No. 6, pp. 330–335. 1903.

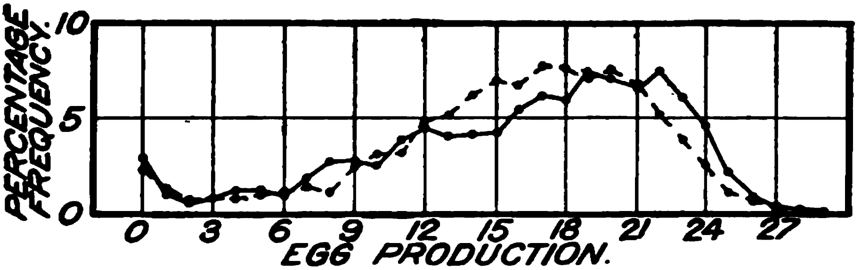

FIG. 21.—Frequency polygon of variation in March and April egg production.

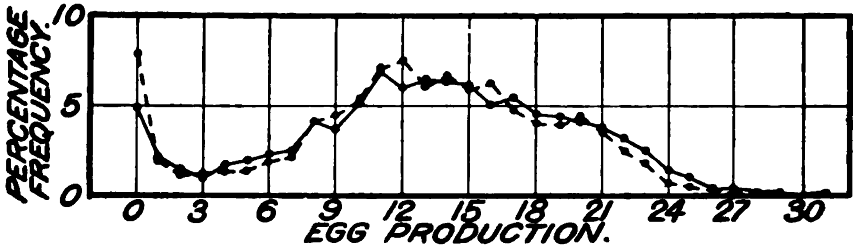

FIG. 22.—Frequency polygon of variation in May and June egg production.

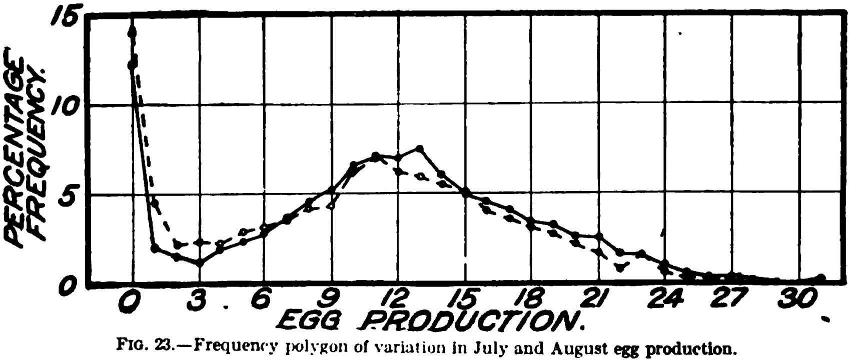

FIG. 23.—Frequency polygon of variation in July and August egg production.

In view of the rarity of types of frequency distribution differing from the common unimodal one, it is of importance to examine with considerable care the nature of these monthly fecundity distributions. To facilitate the discussion of this matter it is desirable to make some preliminary definition of terms necessary to be used in the description of bimodal curves. In the following discussion the terms "upper component" and "lower component" will be used to designate, respectively, the portion of the variation polygons (or, in other words, the groups of variants) centering about the two modes of higher and lower monthly productivity. These terms are here used only in a very general sense and without any attempt to limit precisely the range or the area of either of the components. The two modes about which the components center will be known as the "upper" (i. e., of higher production) and the "lower" (i. e., of lower production) modes, respectively. In discussing bimodal curves it is

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[a] For a list of the literature on this subject see the bibliography in Davenport's Statistical Methods (New York, 1904), and the bibliographical lists appearing currently in Biometrika.

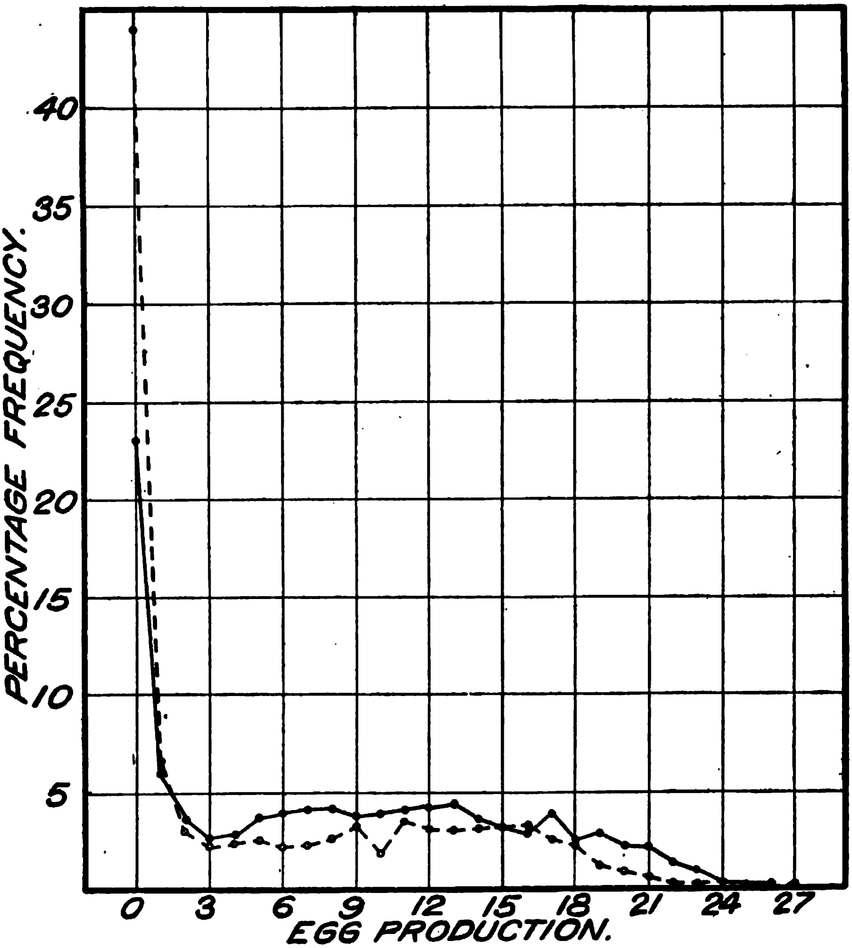

FIG. 24.—Frequency polygon of variation in September and October egg production.

very desirable to have some simple brief term to designate the point on the curve between the two modes where the frequency is at a minimum. It is in this region that the two components of such curves overlap. After careful consideration we have decided to use the term "antimode" to designate the point in any bimodal frequency distribution where the frequency over a unit base element is at a minimum.

POSITION OF MODES AND ANTIMODE IN MONTHLY DISTRIBUTIONS.

Proceeding to the discussion of the monthly distributions, it is to be noted in the first place that the position of the upper mode changes in a definite manner as we pass from the beginning to the end of the laying year. The nature of this change as well as certain other significant facts will be brought out if the position of the observational modes and of the antimode be tabled. These data are given in Table 9. It should be kept in mind that in this table we are only dealing with the highest observed peaks of the distributions, and not with the true modes, the positions of which can only be determined by detailed mathematical treatment of the data. Observational peaks only serve to locate the position of true modes roughly.[a] These observed values will, however, serve for the purposes of the present discussion. In this table the observed mode which has the higher modal ordinate in each of the curves is printed in bold-faced type.

TABLE 9.—*The position (abscissa) of the observational modes and the antimode in the frequency distributions of monthly production.*

[The mode with the higher ordinate is in black-faced type.]

Month.	Position of lower observed mode.	Position of upper observed mode.	Position of antimode.
November	**0**	15	4
December	**0**	18	[b] 15
January	**0**	21	5
February	**0**	18	3
March	0	[c] **20.5**	2
April	0	**17**	2
May	0	**11**	3
June	0	**12**	3
July	**0**	11	3
August	**0**	11	[d] 3
September	**0**	13	3
October	**0**	11	3

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[a] Cf. Pearson, K. Biometrika, Vol. I, pp. 260, 261. 1902.

[b] If this curve were to be smoothed by any accurate process of graduation the antimode would fall at a point considerably below the observed actually smallest ordinate, probably at about 5.

[c] In this distribution there are two observational peaks of equal height in the modal region, one at 19 and one at 22. Rather than take either of these points as the mode it seems fairer from inspection of the polygon to locate the observational mode halfway between the two, viz, at 20.5.

[d] While the ordinates at 2 and 4 in this distribution are slightly smaller than that at 3, inspection shows that in a fitted curve to these observations (say if a parabola were struck through the ordinate at 3 and the four ordinates on either side of 3) the minimum ordinate would fall at about 3.

From this table it is apparent that the upper mode moves steadily upward (i. e., toward a greater egg production) during the first four months of the laying year. It reaches its actually highest point in the March distribution, although if we had available accurately calculated modes it is probable that there would be little difference in the values for March and April. After attaining this maximum point the upper mode moves again toward the zero end of the curve in a rather steady decline. The lower mode falls in every case at the zero abscissa; or, in other words, the "fashionable" production for this component is zero.

Associated with this change in the position of the upper of the two modes is a change in the direction of the skewness, or asymmetry, of the upper component of the distributions. In the distributions for November and December the total area comprised in the upper component is so small that it is difficult without the use of analytical methods to determine what the sign of the skewness is; but, beginning with the January distribution, the direction of the skewness is evident on inspection. The upper component in the January, February, and March distributions shows a definite and considerable negative skewness. This component of the April distribution is probably still negatively skew, though the degree of asymmetry is here very slight. The May distribution shows a marked difference. Here the skewness of the upper component is clearly positive. The mode of this component has now come to lie below (i. e., to the left in the diagram) the mean. Distinct positive skewness is further exhibited by the upper components of the June, July, and August distributions. It is probable that the September and October distributions also have a positive skewness of this component. Here, however, just as in the case of the November and December polygons, the total area comprised in the upper component is so small as to make it impossible to determine this point from mere inspection. Altogether we have here a very interesting case of a variation curve passing gradually and by successive stages from a condition of distinct negative skewness through a symmetrical condition to distinct positive skewness.

RELATIVE HEIGHT OF MODAL ORDINATES.

Another point to be considered is the relative height of the modal ordinates of the two modes in the several distributions. In the earlier months of the year the ordinate of the lower mode is many times higher than that of the upper one. The height of this lower modal ordinate steadily and rapidly decreases month by month until it reaches a minimum in the April distribution. In the months after April it increases again, until it reaches a maximum in the October distribution. In the case of the upper mode the height of the modal ordinate may be said, in general, to increase as the value of the mode increases; that is to say, as the mode of the upper component is located at a higher and higher production up to the maximum in March and April the height of the modal ordinate (i. e., the percentage of the flock laying the modal number of eggs) of this component also becomes greater. The highest observed modal ordinate occurs in the April distribution. After that point the height of the modal ordinate of this component steadily becomes less, until it reaches a minimum in the October distribution. In no one of the distributions, however, does the modal ordinate of the upper component even approximate in magnitude the values attained by that of the lower mode at the ends of the laying year. Or, in other words, the percentage of the flock which lays the most common or usual number of eggs in the natural laying season is always very much smaller than the percentage which lays no eggs at all in the seasons of poor production.

The effect of the change in position of the mode of the upper component and of the changes in the magnitude of the two modal ordinates is well brought out in the following table. The data show that—

One-half (50 per cent) of the flock lays in the month of—	November fewer than 1 egg apiece.
	December fewer than 2 eggs apiece.
	January fewer than 7 eggs apiece.
	February fewer than 10 eggs apiece.
	March fewer than 16 eggs apiece.
	April fewer than 16 eggs apiece.
	May fewer than 13 eggs apiece.
	June fewer than 12 eggs apiece.
	July fewer than 11 eggs apiece.
	August fewer than 10 eggs apiece.
	September fewer than 6 eggs apiece.
	October fewer than 6 eggs apiece.

In only three months of the year do one-half of the birds, according to these statistics, lay more than a dozen eggs apiece in the month.

The antimode in these curves appears to maintain a nearly constant position throughout the year. It is significant that this point of minimum frequency is not at an egg production of 1, but is definitely and clearly at a higher production. This indicates that we are dealing in these distributions with two definite component curves, and not merely with a unimodal distribution with an abnormal frequency on the single base element 0. The frequency over the base elements 1, 2, and probably also 3, in nearly every month, clearly belongs in the main to the lower component as well as that over the base element 0. There is a definite downward slope or "tailing off" of this lower component before the upper component begins. There is some indication that the antimode has a real and definite tendency to lie at a higher point in the earlier months of the laying year (November and December) than in the later ones. This can not be accurately determined, however, without graduation of the raw data.

It appears to be the case that all of these monthly distributions belong to the same general type of frequency curve. This type can be characterized in the following way: The curve is in general S-shaped, as shown in figure 25, presenting two distinct points of maximum frequency or modes.

One limb of the S-shaped curve tends to become asymptotic to the *y* axis. The curve appears to be made up of two distinct components, one of which (the upper) is of the usual "curve of error" type, while the other (the lower) is of the J-shape taken by Pearson's Type III and Type I curves under certain conditions.

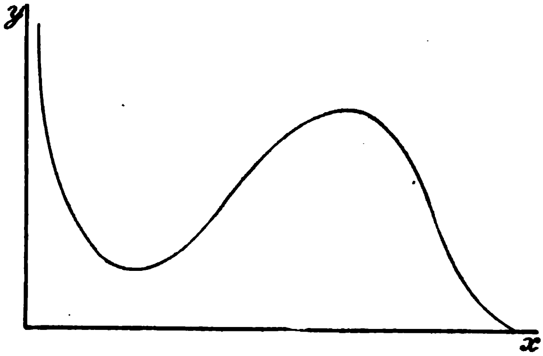

Fig. 25.—Diagram showing the general form or type of curve to which the frequency distributions of variation in monthly production apparently belong.

ANALYSIS OF THE MONTHLY EGG-PRODUCTION DISTRIBUTIONS.

The facts brought out in the last section present a series of problems of much interest. So far as we are aware, S-shaped frequency distributions have not hitherto come to light in any studies of variation in homogeneous material. The question is immediately raised as to what are the biological factors which lead to the development of these curious and unique distributions. It is believed that the results herein to be set forth will throw considerable light on this problem. Since these results are reached by a process of reasoning which has not commonly been employed in biological studies, though it is very often used in the investigation of physical problems by a combination of mathematical and experimental methods, the greatest pains will be taken to set forth as clearly and precisely as possible the steps taken. It is hoped that the present case may serve in some measure to indicate to biological readers the possible utility of biometric methods in a direction not generally recognized.

At the outstart two sets of facts regarding these monthly fecundity distributions need to be recognized. These are:

1. The material in which these bimodal, S-shaped distributions appear is as homogeneous in respect to egg production as is possible in mass selected material. This positive assertion of biometrical

homogeneity for this material can be made because the data come from controlled conditions. The birds were "pure bred" and "line bred." That is, no "strange germ plasm" had been introduced into the race for many generations. Close selection within the race had been practiced in respect to egg production for a long period. The birds made their records in the same place and under essentially the same conditions within the year as far as it was possible to control them. In other words, the peculiarities in the monthly distributions are in no way to be explained as the result of different methods of handling the birds in different months of the year. That egg production is probably inherited in "pure lines" and that this material includes a number of such "pure lines" need not concern us here, since the problem now under discussion is one of the physiology of egg production and not at all one of its inheritance.

An objection may be made to the fact that in the discussion of these monthly distributions the records of eight years have been put together. In regard to this it should be said that this has been done only after the most careful study of the detailed single year data given in Appendix II (Tables I–XII). If anyone will take the trouble to study those detailed data carefully, as we have done, he will find that within the limits of error of random sampling the characteristic distribution for each month is faithfully reproduced every year. The November distribution, for example, is of essentially the same character in 1899 and in 1906. The same is true of the distributions for every month and all of the years. Adding the several years together does not in any way obscure or hide any facts. On the contrary, by providing more ample statistics, it gives smoother curves and enables us (as the outcome proves) to reach a clear understanding of the nature and biological genesis of these monthly fecundity distributions by a method of mathematical analysis which could not successfully be carried out on the much more meager data of a single year.

The writers are well aware of the importance of the statistical canon which says that different sets of data should not be mixed. They would, however, call attention to two facts. In the first place, the essential homogeneity of the present material in regard to the character here under discussion, and so far as concerns strictly the problem of physiology (and not of heredity) with which we are here and now dealing, is in itself a sufficient justification for the statistical procedure followed. In the second place devotion to the letter of a scientific canon should not be so blind as to lose sight of the main purpose of the use of the method involved. The purpose of the present investigation is to learn so far as possible from the available data the true facts regarding the nature and physiological genesis of the monthly fecundity distributions. Thorough study of all the detailed data has convinced us, as it will convince anyone else, we feel sure, who will take the trouble to carry it out, that combining the distributions for the several years greatly helps and in no way hinders us in arriving at a correct and adequate knowledge of the facts.

2. While the material which gives origin to these monthly fecundity distributions is biometrically homogeneous, it is not possible to fit any one of them with a simple unimodal frequency curve. There is no escape from the conclusion that they are compound distributions, even though statistically homogeneous, and must be dealt with as such. This point is emphasized because there is some tendency in biometric work to assert that if a distribution does not fall into the usual simple unimodal type the material is, by virtue of that fact, heterogeneous. This, of course, is not necessarily true. Proof that it is not, if any be needed, is afforded by the curves of monthly fecundity of the present paper or by the well-known curve of human mortality. It is perfectly certain, regardless of the homogeneity of the sample or the population from which it is drawn, that if the number of persons dying at each year of duration of life from 0 to the upper limit at 90+ out of, say, 100,000 born at the same time be platted, the resulting curve will not be a simple unimodal one, but, on the contrary, a compound one. It was shown a number of years ago by Pearson[a] that the human mortality curve is composed of a number of simple frequency curves. The existence of such compound curves in homogeneous material should make one cautious in the use of purely statistical tests of heterogeneity. Any statistical test of heterogeneity which depends upon the discovery of an incipient tendency to bimodality in the data would appear to be valid only in cases where it is a priori certain that the material does not actually follow a compound rather than a simple unimodal frequency curve, even when strictly homogeneous. And, on the other hand, an assertion of homogeneity on the basis of a statistical test alone, without previous knowledge of the biological facts, may be equally liable to be invalid. A very excellent example in this direction, indicating the entirely fallacious result to which a purely statistical test of homogeneity may lead in the absence of biological information as to the detailed facts underlying the statistics, is very well brought out in an example given by Johannsen[b] from some bean measurements.

With these two facts of (1) the homogeneity of the material and (2) the compound character of the distributions clearly in mind, we may turn to the discussion of their analysis.

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[a] Pearson, K. The Chances of Death, Vol. I.

[b] Johannsen, W. Elemente der exakten Erblichkeitslehre, Jena, 1909, p. 122.

At the outstart it is desirable to outline clearly the general method followed in this work. The reasoning developed in the rest of this section may be briefly outlined in the following way:

1. The statement of an hypothesis as to the biological nature and genesis of the S-shaped distributions which in various forms are found to be characteristic of variation in fecundity in the several months of the laying year.
2. The mathematical testing of this hypothesis.
3. The demonstration of its substantial accuracy and adequacy.

The method of procedure here outlined is made necessary by the nature of the problem. We have no a priori knowledge as to why these S-shaped distributions appear. It is not feasible to go further in the direction of experimentally producing them than has been done in getting the present statistics. But we can make a biological hypothesis regarding the distributions. Then it will be possible to test this hypothesis mathematically by determining what the degree of probability is that the actually observed system of frequencies in any given case follows that law of frequency which flows from the biological assumption made. In other words, by a mathematical comparison of observation and theory we can measure the worth of the theory. If the agreement is very close, it is legitimate to conclude that the hypothesis chosen is the correct one.

STATEMENT OF THE HYPOTHESIS.

Careful consideration of the various facts brought out in the preceding section led to the adoption of the following hypothesis as a working basis for further treatment of these curves.

It is assumed—

1. That variations or changes in the rate of fecundity in the hen are fundamentally or innately continuous (in the mathematical sense), though the objective manifestation of fecundity here is discontinuous, i. e., expressed in discrete units. That is to say, the assumption is that if an individual hen's daily egg record ran like this: (A) 1, 0, 0, 0, 1, 1, 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, (B), it would mean, first, that her rate of fecundity was increasing during this period AB, and second, that this increase in rate was continuous throughout the period, so that it might be graphically represented by some kind of a smooth curve, as in the accompanying diagram (fig. 26).

Mathematically expressed, the assumption is that if y denotes rate of fecundity, then

$$y=\phi\ (x,\ t,\ \ldots\ldots\ z)$$

where $\phi\ (x,\ t,\ \ldots\ldots\ z)$ is a continuous function of the several variables, such that any change in the independent variables, however small, will be accompanied by a corresponding change in the dependent variable.

2. That actual, visible egg production in each individual bird tends to occur in definite cycles or periods of varying lengths, alternating with nonproductive periods.

3. That the rate of fecundity (amount of egg production per unit of time conceived in the sense of the differential calculus) is in any bird at a minimum at the beginning of a cycle of production, increases to a maximum at what may be termed the height of the cycle, and decreases to a minimum as the end of the cycle is approached.

4. That each of the monthly fecundity distributions is compound and made up of two parts. It is assumed, in other words, that at any given instant of time in the laying year a flock of laying hens could be separated into two groups if it were possible to know exactly the physiological condition of their reproductive organs. In one group would be included all birds which were at the moment of examination well along in a period of laying activity (or cycle of fecundity). These would be birds whose rate of fecundity was at or above that in the region of B in figure 27. In the other group would be included those birds not laying at all (that is, in a nonproductive condition or period) and those that had just emerged from this condition of zero fecundity and started on a laying cycle. These would be birds whose rate of fecundity was anything from zero up to about A in figure 27.

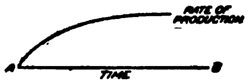

FIG. 26.—Diagram to illustrate the nature of the hypothesis made in the text regarding the rate of egg production.

5. That (*a*) the proportion of the whole flock which falls into each of these two classes, and (*b*) the particular rate of fecundity which marks the boundary between the two classes (the line AB in fig. 27) are not constant, but, on the contrary, change in a definite and orderly manner in the different parts of the laying year.

It is plain that on the hypothesis so far set forth a bird's observed egg production in any given month does not immediately determine in which of the two component classes of the flock it belongs. Let it be supposed, for example, that a particular hen lays 7 eggs in the month of July. The mere knowledge of this fact alone does not tell us whether she laid this small number of eggs because she was just starting on a new cycle of production, or on the other hand because she was just ending a cycle in the previous course of which her rate of fecundity had been much higher than 7 eggs in a thirty-day period. Yet this is what must be known in order to assign her to her proper class.

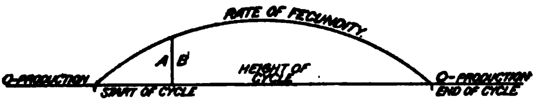

FIG. 27.—Diagram illustrating cycles of fecundity in the hypothesis regarding egg production.

6. That the distribution of frequency within each of the two hypothetical components of the monthly fecundity distributions

follows a simple, unimodal skew frequency curve. In other words, it is assumed that the curve describing the entire monthly fecundity distribution is in each case the sum of two skew frequency curves.

The first of these assumptions needs some further discussion. The idea that egg production is fundamentally a continuous process (in a mathematical sense) may at first thought be difficult to grasp because the objective expression of egg production is in discrete units. But if the various biological steps involved in the production of an egg be once viewed as a whole, there will then be no difficulty in realizing the continuity of the process. Beginning in the young embryo there is the appearance of the primary germ cells in the germinal epithelium. Later, but still in a continuous process of development, the definitive ovary forms. Then the primary oocytes begin to grow. Presently yolk begins to be deposited more or less rapidly, and, finally, at the end of a long but perfectly continuous process of development, the ovum is, by rupture of its inclosing follicle, detached from the ovary, passes down through the oviduct, receiving albumen, membranes, and shell, and is laid as a complete egg. But in the meantime many other oocytes are going through this same process of development and growth. So far as the organism as a whole is concerned, egg production viewed as a whole is a continuous process. The "rate of egg production" clearly means when looked at in a broad way, the rate at which all phases of this complex biological process are going forward at a particular time. This rate varies at different times in the life history of a bird. There may be a definite and positive "rate of fecundity" when a bird is not laying at all. Of course, under such circumstances this rate can not be directly measured, although it can indirectly be estimated. It is the rate at which development of oocytes preparatory to laying is taking place.

The second assumption is really not an assumption at all, but a well-known fact. The third to the sixth assumptions inclusive will be tested in the present work.

The clue to the way in which to make this test is given in the last assumption, which asserts that the observed distributions represent the sum of two frequency curves. If this is in reality the fact it should be possible to graduate or "fit" the observed data satisfactorily with two skew curves, and a successful outcome of the trial would be practically conclusive evidence of the validity of the hypothesis made. If, on the contrary, trial should show that it was impossible to graduate these monthly distributions satisfactorily as the sum of two skew distributions, it would be necessary to conclude that the hypothesis made was either inadequate or entirely incorrect. It is plain that in the practical working out of this matter the decision as to which of these two conclusions shall be drawn will depend on the goodness of fit of the theoretical skew frequency curves to the observed distributions; that is, it will turn on the mathematical criterion of the "satisfactory" or "successful" nature of the graduation. Fortunately in the case of frequency curves we have an effective criterion of the goodness of fit. It was first shown by Pearson[a] that the probability P that a complex system of n errors will occur with a frequency as great or greater than that of the observed system is given by the expression:

$$P=\frac{\int_{\chi}^{\infty} e^{-\frac{1}{2}\chi^2}\ \chi^{n-1}\ d\chi}{\int_{0}^{\infty} e^{-\frac{1}{2}\chi^2}\ \chi^{n-1}\ d\chi},$$

wherein χ is such a quantity that, if m_r and m'_r be respectively the observed and theoretical frequencies in each of the n frequency groups, then

$$\chi^2=S\left\{\frac{(m_r-m'_r)^2}{m_r}\right\}$$

S denoting summation as usual. In the paper cited the complex integrals in the expression for P were evaluated, and the proper equations for P with n odd or even were given. Later Elderton[b] published tables giving the value of P for a rather wide range of values of χ^2 and n. Regarding the significance of this test of the goodness of fit Pearson (*loc. cit.*, p. 166) says:

> Thus I think we can conclude, when we are dealing with a sufficiently long series to give small probable errors to the constants of the series, that—
>
> (*i*) If χ^2_s be so small as to warrant us in speaking of the distribution as a random variation on the frequency distribution determined from itself, then we may also speak of it as a random sample from a general population whose theoretical distribution differs only by quantities of the order of the probable errors of the constants, from the distribution deduced from the observed sample.
>
> (*ii*) If χ^2_s be so large as to make it impossible for us to regard the observed distribution as a sample from a general population following the law of distribution deduced from the sample itself, it will be impossible to consider it as a sample from any general population following a distribution differing only by quantities of the order of the probable errors of the sample distribution constants from that sample distribution. In other words, if a curve is a good fit to a sample, to the same fineness of grouping it may be used to describe other samples from the same general population. If it is a bad fit, then this curve can not serve to the same fineness of grouping to describe other samples from the same population.

What we propose to do, then, is to determine mathematically the probability that, as indicated by our samples, the general population from which these samples may be supposed drawn (i. e., Plymouth Rock pullets in general) follows the system of distribution of fecundity which on biological grounds we have proposed as an hypothesis. The probability determined indicates the degree of probability that the hypothesis is true. Especial effort is made to make this point perfectly clear because at first thought it might appear that the procedure here used is of the same character as that which one of the writers has criticized on a previous occasion.[a] The cases are, however, entirely different. The point which was criticized in the paper referred to was the attempt to prove an essentially *qualitative* hypothesis by the use of *quantitative* methods alone. In the present instance we have made an hypothesis which has to do solely with quantitative characteristics of the physiological process of egg production (fecundity). The proper and strictly logical procedure is to test the validity of this quantitative hypothesis by the use of appropriate quantitative (mathematical) methods.

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[a] Pearson, K. On a criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling. Philosophical Magazine, 1900, pp. 158–175.

[b] Elderton, W. P. Tables for testing the goodness of fit of theory to observation. Biometrika, Vol. I, pp. 155–163. 1901.

THE FITTING OF THE CURVES.

Let us turn now to the fitting of the curves. Inasmuch as the graduation of a frequency distribution as the sum of two skew curves has not hitherto been developed,[b] it was necessary to work out a method of approaching the problem. In doing this we have proceeded in a strictly empirical manner. The limitations of the writers' mathematical attainments forbid the undertaking of a general analytical discussion of the problem of resolving a compound distribution into two skew curves. Our experience, however, in dealing with these distributions in an empirical way has at a number of points suggested strongly that there must exist a general analytical solution of the problem. We would suggest this problem to any unoccupied mathematician as one of considerable theoretical interest, and, if solved, of much practical importance.

The method of approach which has been followed in the present investigation is as follows:

1. To take the area of the sum of the two component skew curves to be equal to the area of the observed distribution.

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[a] Pearl, R. Some recent studies on growth. American Naturalist, Vol. XLIII, pp. 302-316. 1909.

[b] The treatment of a skew curve as the sum of two normal curves was fully worked out by Pearson a number of years ago. See Philosophical Transactions, Vol. 185 A, pp. 71-110. 1894. While the present paper was passing through the press a method of treating certain bimodal curves similar in form to the S-shaped curves here dealt with was published by G. Udny Yule, under the title "On the Distribution of Deaths with Age When the Causes of Death act Cumulatively, and Similar Frequency Distributions." Jour. Roy Stat. Soc. Vol. 73, Part I, pp. (of reprint) 1-13, 1910.

2. To make, by graphical methods, a series of assumptions as to the range, midpoint, and shape of each of the two component distributions.

3. To test the goodness of these assumptions by fitting skew curves to a given pair of assumed components, determining areas, summing the two curves obtained, and then testing how good a fit had been obtained to the whole distribution, using Elderton's tables. If a given assumption gave a high value for P it was concluded that the component curves had been determined adequately enough.

It will be seen that this is a strictly empirical, "cut-and-try" method, but it is not more so than any kind of curve fitting where the appropriate curve to use is not known a priori. In ordinary work it is often impossible a priori to tell whether a third order or a fifth order parabola or a logarithmic curve will best graduate a given set of data. The only way to find out is to try each of the curves and see which gives the best result, taking all known facts into consideration. In all such curve fitting the only general principle which one has as a guide is that "the proof of the pudding is in the eating," not forgetting, of course, the distinction between true graduation methods on the one hand and interpolation methods of fitting or their equivalents on the other hand.

Since the amount of labor involved in dealing with these compound distributions by the method outlined is very great, and since the monthly distributions (with two possible exceptions to be presently considered) are of the same general type, it has seemed neither necessary nor advisable to undertake in detail here the analysis of the distribution for each month. Instead we have chosen for analysis several months which give typical illustrations of the different forms which the S-shaped distributions take in the course of the year. As has been previously shown (pp. 126–132), the distributions in the fall and winter months are characterized by having a very high zero frequency and a rather flat upper component. As an illustration of the extreme deviation of the monthly distributions in this direction November has been chosen for analysis. The other extreme in the shape of the distributions is found in the spring months where the lower component is very small and the high frequencies fall in the upper component. As a typical illustration of the spring type of distribution April has been chosen for analytical treatment. The summer laying leads to distributions which, as has been seen already, are intermediate in form between the extremes mentioned. As an illustration of this intermediate type the month of July has been chosen.

These three months—November, April, and July—fairly represent the different forms taken by the monthly distributions in the different parts of the laying year. Nothing essential to the present discussion will be gained by dealing in detail with the distributions for the other months.

At this point a word should be said in regard to the methods of calculation used in fitting these curves. The raw moments were used in all cases, Sheppard's corrections not being applied. The reason for this was the absence of high contact at one end of the lower component in all cases. Practically all computing was done on a large Millionaire calculating machine, and all possible checks were applied to insure arithmetical accuracy. In calculating the areas of the fitted curve Simpson's quadrature formula

$$\int_0^1 y_x dx = \frac{1}{6}\left\{y_0 + 4y_{\frac{1}{2}} + y_1\right\}$$

was used except for the end class in the case of the J-shaped lower component curves. In these curves the ordinate at the start of the range is infinite, but the area over any base element is finite. Here evidently no quadrature formula is adequate.

An equation for such a case where, as in the present examples, the J-curve is of Type I, is[a]—

$$\int_0^x y_0 x^{m_1}(b-x)^{m_2} dx = y_0 x^{m_1+1} b^{m_2}\left(\frac{1}{m_1+1} - \frac{m_2 x}{b(m_1+2)} + \ . \ . \ .\right)$$

where x is, of course, the distance from the start of the curve where the ordinate is infinite up to the upper limit of the end class to which this ordinate belongs. In using this formula y_0 must be calculated by the formula

$$y_0 = \frac{\mathrm{N}}{b^{m_1+m_2+1}} \cdot \frac{\Gamma(r)}{\Gamma(m_1+1)\,\Gamma(m_2+1)}$$

COMPONENTS AND FITTED CURVES FOR NOVEMBER DISTRIBUTION.

The November distribution may be discussed first, although it was not the first actually to be resolved into two skew curves. Experience with other and more tractable distributions made it possible to hit upon an adequate assumption as to the component curves in this case at the first trial. The assumed component distributions and the fitted curves are given in Table 10. In this table and all the discussion which follows the lower component (small egg production) will be designated as the "A component" and the upper (large production) as the "B component."

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[a] Elderton, W. P. Frequency Curves and Correlation. London, 1907. P. 104.

TABLE 10.—*November egg production, showing the assumed components and their fitted curves.*

Eggs laid in the month.	Assumed A component distribution.	Theoretical A component distribution (areas).	Assumed B component distribution.	Theoretical B component distribution (areas).
0	1,189	1,190		
1	137	132		
2	47	55		1
3	33	30	4	5
4	19	18	7	11
5	10	11	26	17
6	6	6	31	24
7	3	4	29	30
8	2	2	30	36
9	1	1	40	41
10			39	45
11			49	48
12			36	51
13			61	52
14			47	51
15			77	50
16			36	48
17			43	44
18			39	40
19			41	34
20			23	28
21			24	22
22			13	15
23			5	9
24			6	3
Total	1,447	1,449	706	705

The analytical constants of these distributions are given in Table 11. Since the data were not grouped in the calculations, the unit of the constants throughout is one egg.

TABLE 11.—*Analytical constants of variation in November egg production.*

Constant.	A component curve.	B component curve.
N	1447	706
μ_2	1.0698	22.4391
μ_3	4.2481	−4.0612
μ_4	23.4654	1,132.1670
β_1	14.7403	0.0015
$\sqrt{\beta_1}$	3.8393	0.0382
β_2	20.5041	2.2485
β_2-3	17.5041	−0.7515
κ_1	−9.2128	−1.5072
κ_2	−5.8466	−0.0007
Pearson's type	I	II
a_1	−8.7732	
a_2	19.7364	11.5882
m_1	−0.8822	
m_2	1.9847	1.4922
Skewness	+8.8855	0
d	9.1903	0
Standard deviation	1.034±.013	4.737±.085
Mean	0.372±.018	13.347±.120
Mode	−8.8185[a]	13.347±.120
Coefficient of variation	278.184±14.158	35.491±.713
Range	10.9632	23.1764
+ end of range	10.9179	24.9352
− end of range	−0.0453	1.7588

[a] In "J-shaped" Type I curves of this sort the mode ceases to have its usual physical meaning and becomes simply an algebraical constant of the curve. It, of course, still remains the point of origin of x.

From the table the following points are to be noted:

1. Both of the component curves prove to belong to limited range types of Pearson's skew curves. This must be regarded as a first point in favor of the general hypothesis on which we are working. The amount of egg production per bird in a given time interval is a physically limited quantity. Theoretically, then, there is good ground for expecting that the theoretical curves which are to describe the quantitative features of this process should be limited range curves. The estimation of the range given by the curves in the present case is in excellent accord with observed fact. The lower range end of the A component and hence of the whole curve is at —0.045 egg, or practically at 0 egg production. The upper range end of the B component and hence of the whole curve is at 24.93, or practically 25 eggs. The highest observed November production is 24 eggs, but the frequency is unduly high on this class and undoubtedly should be distributed over two or three higher classes.

2. The A component curve is of Pearson's Type I. It belongs in the class of J-shaped curves where one of the *m*'s is negative. The B component is a symmetrical curve of Type II, and has the ordinary "cocked-hat" shape. The absence of skewness in this component is noteworthy.

3. From the figures given it appears that 67 per cent of the flock falls in the A component in the November laying, and 33 per cent in the B component. In other words, according to the hypothesis developed above, it appears that 67 per cent of the flock either are not laying at all in November or have just started to lay, while 33 per cent are well along in a laying cycle in the course of the month.

4. The centroid (mean) of the A component falls within the zero class (0.372 egg). The centroid of the B component is at 13.347, almost exactly 13 eggs higher. It thus appears that while some 33 per cent of the birds are well on in a laying cycle in November, the rate of production, even of these B component birds, is not as high as it becomes later in the year.

5. The B component shows the greater absolute variability (measured by standard deviation). But in proportion to the mean of the character varying (coefficient of variation) it exhibits a much lower variability than the A component. The coefficient of variation of the B component has about the same value as the average for annual production (see Part I, p. 29).

The equations to the curves are:

$$\text{A component } y=71.9022\left(1-\frac{x}{8.7732}\right)^{-.8822}\left(1-\frac{x}{19.7364}\right)^{1.9847}$$

$$\text{B component } y=51.6283\left(1-\frac{x^2}{134.2861}\right)^{1.4922}$$

The November distribution and its fitted curves are shown graphically in figure 28.

We have now to consider the question of the closeness of agreement between observation and theory for the November egg production. It is evident from figure 28 that in general the fit of the combined A and B component curves to the observations is close. The general sweep of the observations is satisfactorily accounted for by the theoretical curve. In applying Pearson's test of the goodness of fit here, however, there are some points which need preliminary consideration. In the first place it has to be recognized that, while our sample is fairly large as statistical data in biology go, yet over 50 per cent of the total frequency in this case falls in one class (zero egg production). Further, since the data are ungrouped, it results that the remaining frequency is spread over a large number of classes (24). This means that the frequency on any class except 0 will be small, and hence, with a character so highly variable absolutely and

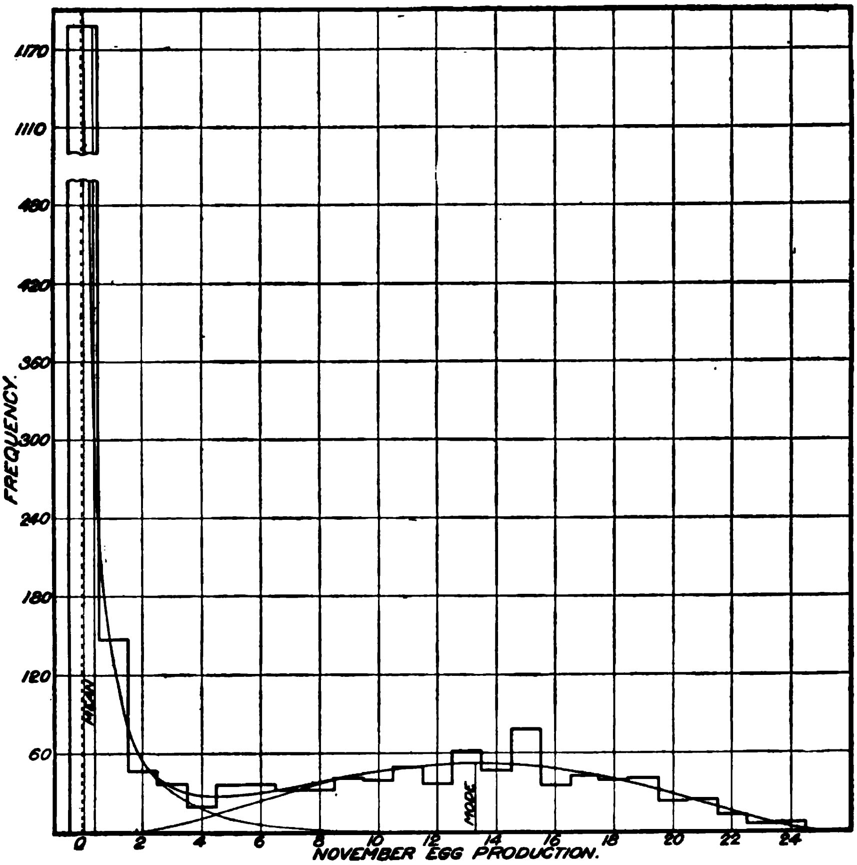

FIG. 28—Histogram and fitted curves for November egg production.

relatively as egg production is, it can not be expected that a sample of anything like the size of the present one will give a smooth distribution. Figure 28 plainly shows that there is a great deal of irregularity in individual frequencies in the B component part of the distribution. Such irregularity is only what is to be expected in a distribution of the shape of the present one, when the sample is no larger than this is. As a result of this irregularity due to the smallness of the sample in relation to the number of classes showing a frequency, the value of χ^2 may be made very large as the effect of one or two irregular classes, even though the theoretical curve represents very precisely the general sweep of the observations. In view of these facts it seems advisable to smooth the minor irregularities of the individual classes in the B component, which have no relation to the general form of the curve. This will help to make the application of Pearson's test a fair measure of the goodness of fit of the whole curve to the observations. We have accordingly made a graphical "first smooth" of the observations from class 10 on to the end of the curve. The smoothing is started at 10 because the A component curve ends at 9. In other words, no smoothing is done in the critical region of the curve where both A and B components contribute to the final result.

In Table 12 Pearson's test of the goodness of fit is applied successively to the rough and the smoothed observations.

TABLE 12.—*Comparison of observed and theoretical November egg production distributions.*

Eggs laid in month.	Observed total distribution.	"First smooth" of observations beyond end of range of A component.	Theoretical total distribution (areas).	$\frac{(m_r-m'_r)^2}{m_r}$ Raw data.	$\frac{(m_r-m'_r)^2}{m_r}$ "First smooth."
0	1,189	1,189	1,190	0.001	0.001
1	137	137	132	.189	.189
2	47	47	56	1.446	1.446
3	37	37	35	.114	.114
4	26	26	29	.310	.310
5	36	36	28	2.286	2.286
6	37	37	30	1.633	1.633
7	32	32	34	.118	.118
8	32	32	38	.947	.947
9	41	41	42	.024	.024
10	39	42	45	.800	.200
11	49	43	48	.021	.521
12	36	45	51	4.412	.706
13	61	51	52	1.558	.019
14	47	58	51	.314	.961
15	77	59	50	14.580	1.620
16	36	47	48	6.750	.021
17	43	40	44	.023	.364
18	39	40	40	.025	.400
19	41	37	34	1.441	.265
20	23	27	28	.893	.036
21	24	20	22	.182	.182
22	13	13	15	.267	.267
23	5	7	9	1.778	.444
24	6	4	3	3.000	.333
Total	2,153	2,147	2,154	43.112	13.407

From the table the following points are to be noted:

1. As the raw observations stand, Pearson's test would indicate that the theoretical curve gives an extremely poor graduation. For $n=25$ and $\chi^2=40$, Elderton's table gives $P=0.021387$, or on this result it would be expected that 98 or 99 times in every 100 trials we should be likely to get a better agreement between observation and theory than that here shown if samples were taken from a general population following the law of frequency given by the theoretical curve.

2. But it is clear from figure 28 that the curve is by no means so bad a fit as this would indicate. On the contrary, it is a plain and obvious fact that the curve gives a very excellent representation of the general sweep of the observations. In other words, the curve gives a satisfactory graduation of the data as a whole, though in so doing it necessarily quite fails to hit a few (actually 4) very irregular class frequencies.

3. An analysis of the χ^2 column for the raw data shows that this value of 43.112 owes its extreme magnitude chiefly to the contributions from 4 classes, viz, 12, 15, 16, and 24. Class 15 alone adds 14.580 to χ^2. A study of the detailed figures in this column in connection with figure 28 will serve to convince anyone that the value of P obtained from the raw data in this case merely signifies that the curve fails entirely to fit 4 out of the 25 observed class frequencies. It gives no proper measure at all of the validity of the graduation of the data as a whole.

4. Such a measure is much more accurately given by the figures in the last column of the table. Here the theoretical curve and the observations graphically smoothed (in a nonarbitrary manner) in the part of the distribution beyond the end of the A component range are compared. Here we get $\chi^2=13.407$. Elderton's tables show that for $n=25$, $P=0.966121$ when $\chi^2=13$ and 0.946650 when $\chi^2=14$. In other words, if samples of the size of the present one were drawn from a population obeying the law of frequency given by the theoretical curve, only about 5 times in every 100 trials should we expect to get as close or closer agreement between observation and theory than the present figures show.

5. Taking all the facts into consideration, it appears that the theoretical compound frequency curve obtained as the sum of two skew curves so closely fits the observations that it may be inferred with a high degree of probability that what differences exist between observation and theory arise only as a result of the errors of random sampling. From this the conclusion would seem to be justified (according to the principles set forth in the quotation from Pearson, p. 139) that the distribution of November egg production is, in general, compound in character, as postulated in our original hypothesis.

COMPONENTS AND FITTED CURVES FOR APRIL DISTRIBUTION.

Let us turn now to the consideration of the April distribution. The assumed components and their fitted curves are given in Table 13.

TABLE 13.—*April egg production, showing the assumed components and their fitted curves.*

Eggs laid in the month.	Assumed A component distribution.	Theoretical A component distribution (areas).	Assumed B component distribution.	Theoretical B component distribution (areas).
0	55	48	....	1
1	28	29	1	2
2	13	18	3	3
3	11	12	8	6
4	8	8	10	9
5	4	5	19	15
6	2	3	23	21
7	1	1	32	31
8	....	....	28	42
9	....	....	58	56
10	....	....	76	72
11	....	....	79	90
12	....	....	119	108
13	....	....	125	127
14	....	....	150	146
15	....	....	168	162
16	....	....	162	175
17	....	....	186	183
18	....	....	185	186
19	....	....	171	181
20	....	....	184	169
21	....	....	164	151
22	....	....	124	126
23	....	....	95	97
24	....	....	63	66
25	....	....	29	38
26	....	....	15	16
27	....	....	5	3
28	....	....	3	....
Total	122	124	2,285	2,282

The analytical constants for these distributions are given in Table 14.

TABLE 14.—*Analytical constants of variation in April egg production.*

Constant.	A component curve.	B component curve.
N	122	2285
μ_2	2.6506	22.2406
μ_3	5.6934	−41.7310
μ_4	28.4613	1387.6466
β_1	1.7406	0.1583
$\sqrt{\beta_1}$	1.3193	0.3977
β_2	4.0509	2.8053
β_2-3	1.0509	−0.1947
κ_1	−3.1199	−0.8642
κ_2	−0.6314	−0.1436
Pearson's type	I	I
a_1	−7.8617	25.4224
a_2	15.6646	10.1462
m_1	−0.5239	6.7437
m_2	1.0438	2.6914
Skewness	5.7344	−0.2832
d	9.3360	−1.3355
Standard deviation	1.628±.070	4.716±.047
Mean	1.295±.099	16.539±.067
Mode	−8.0409	17.8747
Coefficient of variation	125.712±11.072	28.514±.307
Range	7.8029	35.5686
+end of range	7.6237	28.0208
−end of range	−0.1792	−7.5478

From this table we note the following points:

1. As in the case of the November distribution, both of the component curves are of limited range. In this case both are of Type I, the A component curve being, as before, of the J-shape. The estimation of the range ends is in close accord with the facts in the A component curve, giving the lower at -0.1792 or practically zero and the upper at 7.6237. The upper end of the B component (28.0208) falls a little short of the observational range, but not badly so. The lower end of the B curve is at -7.5 roughly, which is, of course, a physically impossible value. However, no particular importance is to be attached to this fact, because the frequency in this component below the zero class is negligible.[a]

2. The values of the areas show that in the April laying only a trifle more than 5 per cent of the total flock falls in the A component of the curve, while 95 per cent falls in the B component. This result agrees very well with common experience that in April, which represents about the height of the natural breeding season, practically all of the birds are well along in a laying cycle.

3. The mean of the A component falls at 1.295, about 1 egg higher than in the case of the November distribution. The mean of the B component is at approximately 16.5 eggs, showing an increase of about 3 eggs over the November B component.

4. The absolute variabilities of the two components stand in about the same relation to each other as in the November curve. The A component is, however, somewhat more variable absolutely in this curve than in the other. Relatively (as measured by the coefficient of variation) both components have a lower variability in the April than in the November curve.

5. The B component in this curve is skew in the negative direction (mode larger than mean), though the asymmetry is not great in amount.

The equations of the curves are—

$$\text{A component } y=25.93\left(1-\frac{x}{7.8617}\right)^{-0.5239}\left(1-\frac{x}{15.6646}\right)^{1.0438}$$

$$\text{B component } y=185.91\cdot\left(1+\frac{x}{25.4224}\right)^{6.7437}\left(1-\frac{10.1462}{x}\right)^{2.6914}$$

The distribution and fitted curves are shown graphically in figure 29.

It is apparent from the figure that the agreement between observation and theory in this case is, in general, excellent. Here the small area comprised in the A component leaves relatively large frequencies for the remaining portion of the curve. The detailed figures for the Pearson test of the goodness of fit are given in Table 15.

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[a] See Part I, pp. 32–38, for a discussion of this matter of the extension of the range into negative values.

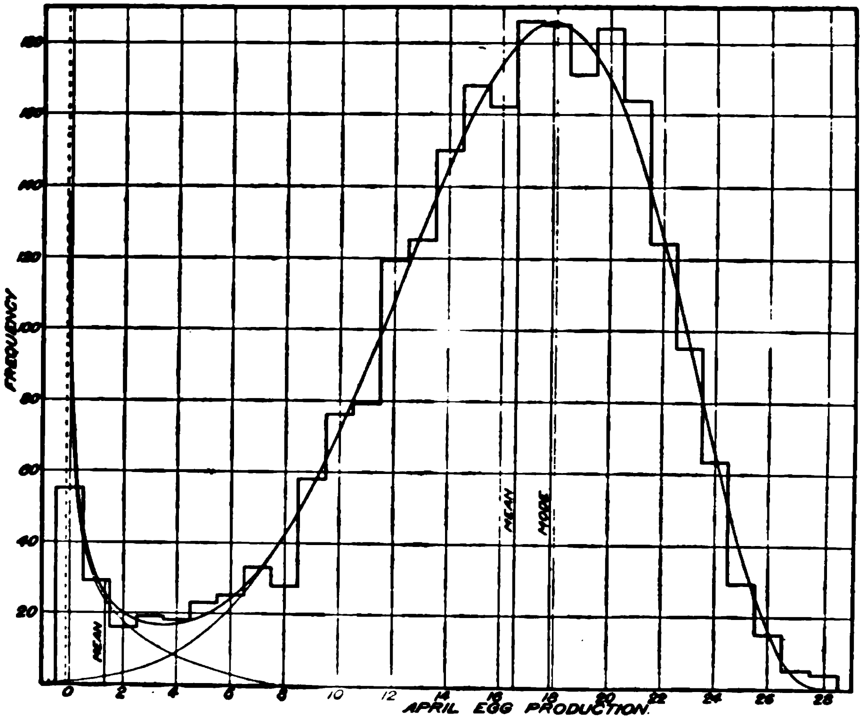

FIG. 29.—Histogram and fitted curves for April egg production.

TABLE 15.—*Comparison of observed and theoretical April egg-production distributions.*

Eggs laid in the month.	Observed total distribution.	Theoretical total distribution (areas).	$\frac{(m_r-m'_r)^2}{m_r}$
0	55	49	0.735
1	29	31	.129
2	16	21	1.190
3	19	17	.235
4	18	17	.459
5	23	20	.450
6	25	24	.042
7	33	32	.031
8	28	42	4.667
9	58	56	.071
10	76	72	.222
11	79	90	1.344
12	119	108	1.120
13	125	127	.032
14	150	146	.110
15	168	162	.222
16	162	175	.966
17	186	183	.049
18	185	186	.005
19	171	181	.552
20	184	169	1.331
21	164	151	1.119
22	124	126	.032
23	95	97	.041
24	63	66	.136
25	29	38	2.132
26	15	16	.063
27	5	3	1.333
28	3		
Totals	2,407	2,405	18.418

The figures in this table support the conclusion reached from an examination of the curve. From Elderton's table it appears that when $n=28$ and $\chi^2=18$, $P=0.903519$, and when $\chi^2=19$, $P=0.870001$. Or, in other words, the figures indicate that if the distribution of April egg production in Barred Plymouth Rock pullets followed exactly the law given by the combined theoretical curves we should expect to get a better agreement between observation and theory when tested by random samples of the size of the present one in only about 11 or 12 out of every 100 trials. The graduation is excellent, and may be taken to indicate with the degree of probability implied in the above figures that the general hypothesis regarding the quantitative characteristics of egg production is true for April production.

COMPONENTS AND FITTED CURVES FOR JULY DISTRIBUTION.

Let us turn next to the July distribution. The final assumed component distributions and their fitted curves are given in Table 16.

TABLE 16.—*July egg production, showing the assumed components and their fitted curves.*

Eggs laid in the month.	Assumed A component distribution.	Theoretical A component distribution (areas).	Assumed B component distribution.	Theoretical B component distribution (areas).
0	297	296		0.2
1	42	45	6	2
2	26	23	9	7
3	14	15	13	17
4	10	11	32	32
5	7	6	48	50
6			65	71
7			86	93
8			110	113
9			125	130
10			157	143
11			168	151
12			164	154
13			167	152
14			144	145
15			119	135
16			109	122
17			95	107
18			81	91
19			79	75
20			60	61
21			59	48
22			36	36
23			35	25
24			20	18
25			11	12
26			6	8
27			4	5
28			1	3
29			0	1
30			0	1
31			2	0.3
Totals	396	396	2,011	2,008.5

The analytical constants of these distributions are given in Table 17.

TABLE 17.—*Analytical constants of variation in July egg production.*

Constant.	A component curve.	B component curve.
N	396	2011
μ_2	1.2489	24.8575
μ_3	3.2640	37.1164
μ_4	12.3682	1703.9598
β_1	5.4687	0.0897
$\sqrt{\beta_1}$	2.3385	.2995
β_2	7.9293	2.7577
β_2-3	+4.9293	−.2423
κ_1	−6.5474	−.7537
κ_2	−1.6290	−.0916
Pearson's Type	I	I
a_1	7.1849	12.9692
a_2	−1.6429	26.3983
m_1	−0.8576	3.7155
m_2	0.1961	7.5628
Skewness	−5.9014	0.2029
d	−6.5951	1.0114
Standard deviation	1.476±.035	4.986±.075
Mean	0.533±.050	13.053±.053
Mode	[a] 7.1279	12.0413
Coefficient of variation	276.922±26.830	38.197±.462
Range	5.5420	39.3675
+end of range	5.4851	38.4397
−end of range	−0.0570	−0.9278

[a] The "mode" here is, of course, merely an algebraical constant of the curve.

From these figures we note that—

1. Both component curves are again limited-range Type I curves. The A component curve is of the J-shaped type. The theoretical estimation of the range by these curves is, as in the other curves, in good accord with observed fact. The lower range end of the A component falls almost exactly at 0 production, while the same end of the B component is at −0.9, an insignificant overestimation. The upper end of the B component (and hence of the compound curve) is at about 38 eggs. This is higher than the observed range end, but the theoretical frequency (area of the curve) beyond the latter is negligible in amount.

2. In the July distribution approximately 16.5 per cent of the total frequency falls in the A component and 83.5 per cent in the B component. This indicates the decreasing rate of fecundity in July as compared with April.

3. The mean of each component is lower than the mean of the corresponding component of the April curve. The mean of the B component (13.053) is very nearly the same as the mean of the November B curve (13.347). In other words, the birds which are fairly well started on a laying cycle lay at about the same rate in November as in July.

4. The relative variability of the A component becomes again very high, practically equaling the November variability. The B component shows relatively more variability than in either of the other curves examined.

5. The skewness of the B component is here positive, the mode lying below the mean.

The equations of the curves are—

$$\text{A component } y=0.8234\left(1+\frac{x}{7.1849}\right)^{-0.8576}\left(1+\frac{x}{1.6429}\right)^{0.1961}$$

$$\text{B component } y=154.44\Big((1+\frac{x}{12.9692}\Big)^{3.7155}\left(1-\frac{x}{26.3983}\right)^{7.5628}$$

The fitted curve is shown graphically in figure 30.

It is evident from the diagram that the graduation is a good one. Applying Pearson's test of the goodness of fit, we have the results set forth in Table 18.

TABLE 18.—*Comparison of observed and theoretical July egg-production distributions.*

Eggs laid in the month.	Observed total distribution.	Theoretical total distribution.	$\frac{(m_r-m'_r)^2}{m_r}$
0	297	296	0.003
1	48	47	.021
2	35	30	.833
3	27	32	.781
4	42	43	.023
5	55	57	.070
6	65	71	.507
7	86	93	.527
8	110	113	.080
9	125	130	.192
10	157	143	1.371
11	168	151	1.914
12	164	154	.649
13	167	152	1.480
14	144	145	.007
15	119	135	1.896
16	109	122	1.385
17	95	107	1.346
18	81	91	1.099
19	79	75	.213
20	60	61	.016
21	59	48	2.521
22	36	36	.000
23	35	25	4.000
24	20	18	.222
25	11	12	.083
26	6	8	.500
27	4	5	.200
28	1	3	1.333
29	0	1	1.000
30	0	1	1.000
31	2	[a] 1	1.000
Total	2,407	2,406	26.272

[a] Total area of theoretical curve for 30 and beyond.

Elderton's tables extend only to $n=30$. By graphical extrapolation from these tables we find that for $n=32$ and $\chi^2=26$, P is roughly 0.72. In other words, it appears that while the graduation of the July data is not quite so good as that of the April, it still can only be regarded as excellent. If egg production in July followed exactly the law of frequency given by the present theoretical curve, we should expect to get a better agreement between observation and theory when tested by random samples of the size of the present one in only one sample out of every three or four tried.

It appears, taking all the evidence together, that there is a very high degree of probability that the hypothesis made above (p. 136 et seq.) regarding the quantitative relations of egg production is true. We have found a very close accordance between observation and theory in the case of three months chosen as examples to represent the different types of distribution which appear in the different parts of the laying year. There is an accumulative probability, arising from the fact that all three of these distributions show such excellent agreement between observation and theory, that the hypothesis adopted represents in essential features the actual facts. So great is this probability that the evidence presented may be said practically to demonstrate the validity of the hypothesis advanced, so far at least as the months specially discussed are concerned.

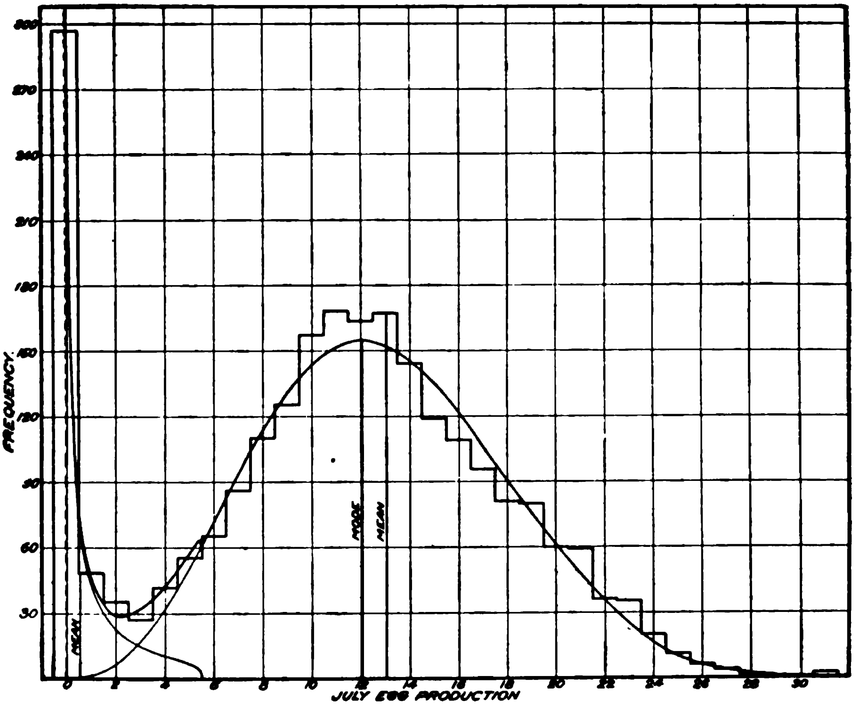

FIG. 30.—Histogram and fitted curves for July egg production.

CONFORMITY OF REMAINING MONTHS TO GENERAL TYPE.

It now remains to consider briefly the question of the extent to which the other months of the year conform to the general type of S-shaped compound distribution of egg production which have been analyzed for November, April, and July. The facts brought out in the preceding section leave little doubt that all the months are of essentially this same type. The only months regarding which there can be any doubt on this point are December and January, and here the doubt is not as to whether these curves are compound and S-shaped, but merely as to whether it may not be necessary in graduating them to make a subsidiary hypothesis in addition to that which suffices for the treatment of the other months. In the observed distributions for these months there is an unduly high frequency on the classes lying in the boundary region where the two components overlap. An analytical study of the January distribution shows that the unsmoothed figures are not so readily to be graduated satisfactorily as the sum of two curves as the other months have proved to be. However, this result by no means proves that another law of frequency obtains for December and January. This will be evident if the following facts are taken into consideration. December and January are both months showing the extreme type of distribution with a very high frequency on zero, and consequently, with samples of the present size, have an entirely inadequate remaining frequency to give a smooth distribution over the other classes. In other words, we have the same difficulty as has been noted for the November distribution, though here possibly more pronounced. Any existing difficulty in regard to the graduation of the polygons of these months may arise simply because the existing sample is a particularly bad one from which to determine the true nature of the distribution. The conclusion to which the facts point is that the December and January distributions are in their general features like those for the other months of the year, which, as we have seen, represent the sum of two skew frequency curves. With our present data, however, we are not able to determine whether or not some minor additional subsidiary hypothesis may be necessary to graduate satisfactorily the distributions for these two months. This is a question of detail which must wait for further data. It does not influence the general result of this investigation.

A special summary of the points brought out in this section of the paper is not given here, but in order to save space, is presented in the general summary of the whole paper which immediately follows:

SUMMARY OF RESULTS AND CONCLUSIONS.

This paper constitutes Part II of a general study of egg production in the domestic fowl. It deals with the seasonal distribution of egg production. The distribution of egg production in each month of the pullet-laying year is particularly studied. The data on which this study is based are the trap-nest records of Barred Plymouth Rocks collected at the Maine Experiment Station, involving detailed monthly egg records of more than 2,400 birds, collected in a period of nine consecutive years. The chief results of this analysis are summarily stated in the following paragraphs:

1. The mean or average monthly egg production exhibits the following characteristic changes in the course of the laying year:

(*a*) The lowest mean production of the year is in the month of November.

(*b*) The mean monthly production increases in December and January at a relatively very rapid rate.

(*c*) There is a slacking up in the rate of increase in February, which probably represents the point of the ending of the first, or winter, cycle of egg production. This February slacking up amounts in many cases to an actual decrease in productiveness as compared with the point attained in January.

(*d*) The mean production reaches a maximum in March.

(*e*) While the mean production for April is practically the same as that for March, there is a steady decline after April on to the end of the laying year in October.

(*f*) There is a tendency toward a slightly larger drop in mean production in May. This is the period of natural broodiness.

2. The present data indicate that only a trifle more than a quarter of the total eggs produced are laid in the winter third of the year (November 1 to March 1). In the first two-thirds of the laying year approximately three-fourths of the total eggs are produced.

3. The month of maximum productivity varied in the experiments furnishing the present data with the method of housing. In a closed, warmed house the month of maximum production was April; in a curtain-front house it was March.

4. The greatest relative variability in egg production is at the beginning of the laying year (month of November). The month of lowest variability, both absolute and relative, is April.

5. The laying year may be divided into four natural periods or cycles with reference to egg production. The first of these periods (roughly November 1 to March 1) is the winter period, wherein egg production is essentially a nonnatural (i. e., forced or stimulated) process. The second or spring period (roughly March 1 to June 1) is the natural laying period of the domestic fowl in its normal reproductive cycle. The third (roughly June 1 to September 1) and fourth (roughly September 1 to October 31) periods are not sharply separated from one another. The summer egg production represents in part a natural continuance of the normal breeding season (rearing of a second brood by the wild *Gallus*) and in part a stimulated process. This period is terminated by the molt, which is the characteristic feature of the fourth period.

6. There is no evidence that the continued selection for higher egg production practiced during the eight years covered by the experiment produced any increase whatever in the mean egg production

of any month in the year. On the contrary, the mean production in all but two of the months actually decreased during the period of selection.

7. So far as there was any change whatever in variability in monthly egg production during the period when selective breeding was practiced, this change was not in the direction of a reduction as a result of the selection, but, on the contrary, there was an actual increase in variability in all but one month of the year, and here the platted variability line did not sensibly deviate from the horizontal.

8. The present statistics show no bad effect on egg production in the winter months (November to March) of keeping birds in large and crowded flocks (up to the limits included in the present study). On the other hand, overcrowding tends distinctly to lower summer (and to a smaller extent spring) egg production. It is chiefly as a result of this effect on summer production that the mean annual production is lower in the large flocks, as shown in Part I of this work (Bureau of Animal Industry Bulletin 110, Part I, pp. 58–61).

9. The excess in relative variability of egg production of the larger flocks (100 and 150 birds) over the smaller (50 and 100 birds) observed in the annual records (see Part I) is found upon analysis to be on the whole fairly evenly distributed over the whole year. In the period of the year in which there is the heaviest production, such environmental differences as are implied in the different flock sizes in the experiment do not appreciably affect the relative variability of production.

10. The polygons of variation in monthly egg production are all bimodal, though homogeneous. The position of the mode changes in a regular manner during the course of the laying year, as does also the skewness of this portion of the distributions. These monthly distributions may be described as S-shaped, and are in general of the same type in the different months, though different in detail.

11. By a process of mathematical reasoning set forth in detail in the text it is shown that the observed facts regarding the character of the distributions of variation in monthly egg production are adequately accounted for by an hypothesis which includes the following points. These statements are therefore set down as conclusions of this study:

(*a*) That variation or changes in the rate of fecundity in the hen are fundamentally or innately continuous (in the mathematical sense), though the objective manifestation of fecundity is discontinuous, i. e., expressed in discrete units.

(*b*) That visible egg production in each individual bird tends to occur in definite cycles or periods of varying length which alternate with nonproductive periods.

(*c*) That the rate of fecundity (amount of egg production per unit of time, conceived in the sense of the differential calculus) is in any bird at a minimum at the beginning of a cycle of production, increases to a maximum at what may be termed the height of the cycle, and decreases to a minimum (usually quite rapidly) as the end of the cycle is approached.

(*d*) That each of the monthly fecundity distributions is compound, and made up of two parts. In one part are included all birds which are well along in a period of laying activity (or cycle of fecundity). The other part includes those birds not laying at all (that is, in a nonproductive condition or period) and those that have just emerged from this condition of zero fecundity and started on a laying cycle.

(*e*) That (1) the proportion of the whole flock which falls into each of these two classes, and (2) the particular rate of fecundity which marks the boundary between the two classes, are not constant, but, on the contrary, change in a definite and orderly manner in the different parts of the laying year.

(*f*) That the distribution of frequency within each of the two hypothetical components of the monthly fecundity distributions follows a simple, unimodal skew frequency curve, and that the curve describing the entire monthly fecundity distribution is in each case the sum of two skew frequency curves.

APPENDIX II.

In the following 12 tables are given the raw data on which the present paper is based:

TABLE I.—*Frequency distribution of egg production for the month of November.*

Laying year.	Number of hens laying number of eggs designated in box head.[a]																															Total hens.
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1899–1900	39	1	3	0	2	1	3	1	4	2	0	2	2	1	3	1	0	2	2	0	0	1	0	0	0	0	0	0	0	0	0	70
1900–1901	54	5	1	1	2	4	1	2	1	3	1	1	0	1	0	2	2	2	1	0	0	1	0	0	0	0	0	0	0	0	0	85
1901–2	26	1	1	1	1	0	0	1	0	0	3	0	1	1	1	0	1	1	2	1	2	1	1	1	1	0	0	0	0	0	0	48
1902-3	76	5	0	1	2	3	4	4	5	5	4	2	3	3	0	5	1	2	6	4	1	6	3	2	0	0	0	0	0	0	0	147
1903–4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1904-5:																																
50-bird pens	180	12	7	2	1	2	3	1	0	3	3	0	3	5	6	16	6	2	5	5	7	9	2	1	2	0	0	0	0	0	0	283
100-bird pens	45	5	2	1	0	1	1	0	3	1	1	1	0	5	1	9	0	4	1	8	1	0	2	0	0	0	0	0	0	0	0	92
150-bird pens	72	9	4	3	0	0	1	0	1	1	2	3	0	12	0	15	1	8	1	6	0	0	0	1	0	0	0	0	0	0	0	140
1905–6:																																
50-bird pens	70	15	6	2	2	3	4	1	3	3	7	9	7	9	7	8	2	7	7	4	2	0	0	0	0	0	0	0	0	0	0	178
100-bird pens	75	17	4	8	6	5	2	4	3	4	4	8	4	4	11	4	3	6	4	3	2	1	0	0	0	0	0	0	0	0	0	182
150-bird pens	160	16	7	5	2	6	5	5	6	6	6	9	4	11	9	9	6	2	1	0	0	0	0	0	0	0	0	0	0	0	0	275
1906–7:																																
50-bird pens	107	14	1	7	3	6	10	4	2	6	3	3	5	4	5	1	1	1	2	1	0	0	1	0	0	0	0	0	0	0	0	187
100-bird pens	120	16	3	3	0	1	1	3	3	3	3	3	4	2	1	2	4	3	2	2	2	3	1	0	0	0	0	0	0	0	0	185
150-bird pens	165	21	8	3	5	4	2	6	1	4	2	8	3	3	3	5	9	3	5	7	6	2	3	0	3	0	0	0	0	0	0	281
Total birds	1,189	137	47	37	26	36	37	32	32	41	39	49	36	61	47	77	36	43	39	41	23	24	13	5	6	0	0	0	0	0	0	2,153

[a] The figures in the box head indicate the number of eggs laid respectively by the number of hens shown below in each column; e. g., in November, 1899, there were 39 hens that laid no eggs, 1 hen that laid 1 egg, 3 hens that laid 2 eggs, etc.

Laying year.	Number of hens laying number of eggs designated in box head.																															Total hens.
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1899-1900	24	1	3	0	0	1	1	1	2	0	0	0	1	1	3	3	4	4	5	2	4	2	5	1	1	0	0	0	1	0	0	0	70
1900-1901	37	1	2	2	2	0	2	1	0	2	2	1	1	2	2	4	3	1	3	4	3	2	3	1	3	1	0	0	0	0	0	0	85
1901-2	10	0	0	2	1	1	1	1	1	2	2	0	3	1	1	0	5	2	0	2	4	2	1	1	4	1	0	0	0	0	0	0	48
1902-3	75	3	4	7	5	6	5	4	5	6	3	4	2	1	1	0	3	2	3	0	3	1	3	1	0	0	0	0	0	0	0	0	147
1903-4	79	21	15	6	10	7	12	10	11	9	19	11	10	9	5	6	3	2	4	4	1	0	0	0	0	0	0	0	0	0	0	0	254
1904-5:																																	
50-bird pens	150	10	4	3	8	6	5	4	6	7	7	4	4	6	8	4	3	4	11	10	1	6	6	4	1	1	0	0	0	0	0	0	283
100-bird pens	15	4	1	5	2	2	1	3	2	4	2	3	1	5	8	4	6	5	6	1	6	2	1	1	2	0	0	0	0	0	0	0	92
150-bird pens	43	7	3	2	1	2	1	2	3	6	5	6	5	3	4	2	7	5	10	9	4	1	5	3	1	0	0	0	0	0	0	0	140
1905-6:																																	
50-bird pens	59	8	4	3	4	1	0	4	2	1	3	6	5	8	2	2	5	3	10	12	8	6	8	6	4	2	1	1	0	0	0	0	178
100-bird pens	43	11	6	8	9	4	3	3	5	4	4	4	5	6	2	2	4	4	6	7	8	8	7	10	5	3	1	0	0	0	0	0	182
150-bird pens	94	15	6	2	4	4	4	8	4	3	10	3	3	7	4	5	2	10	13	11	16	11	8	13	8	5	0	2	0	0	0	0	275
1906-7:																																	
50-bird pens	95	13	5	5	4	5	6	4	5	7	1	4	4	1	4	0	3	6	2	1	2	6	2	1	1	0	0	0	0	0	0	0	187
100-bird pens	94	10	0	3	3	3	5	2	4	1	3	2	5	2	5	2	12	3	6	7	4	2	3	0	3	0	1	0	0	0	0	0	185
150-bird pens	88	19	14	3	10	15	3	6	9	6	6	4	5	3	10	11	12	9	8	10	7	7	4	7	2	2	1	0	0	0	0	0	281
Total birds	906	123	67	51	63	57	49	53	59	58	67	52	54	55	59	45	72	60	87	80	71	56	56	49	35	15	4	3	1	0	0	0	2,407

TABLE III.—*Frequency distribution of egg production for the month of January.*

Laying year.	Number of hens laying number of eggs designated in box head.																															Total hens.
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1899–1900	3	0	2	1	0	0	0	1	1	2	2	2	2	2	4	4	4	2	4	5	1	9	8	3	5	3	0	0	0	0	0	0	70
1900–1901	9	3	2	3	2	4	2	2	2	5	4	1	1	5	1	3	4	1	4	5	6	3	5	5	2	0	0	1	0	0	0	0	85
1901–2	0	0	0	1	3	0	0	2	2	1	3	0	3	3	0	4	4	5	1	0	2	7	6	0	0	1	0	0	0	0	0	0	48
1902–3	76	6	1	4	3	0	3	1	3	4	2	2	2	6	6	4	2	5	0	6	3	1	5	2	0	0	0	0	0	0	0	0	147
1903–4	52	22	10	9	10	7	10	5	3	7	13	6	8	11	8	8	10	12	9	9	9	11	3	1	1	0	0	0	0	0	0	0	254
1904–5:																																	
50-bird pens	81	4	7	4	8	6	8	5	8	3	10	5	8	7	11	11	13	6	16	9	16	16	11	4	1	2	2	1	0	0	0	0	283
100-bird pens	13	5	0	1	1	2	8	2	2	4	3	3	3	5	5	4	3	5	3	6	6	6	1	1	0	0	0	0	0	0	0	0	92
150-bird pens	28	4	1	4	3	8	2	4	8	2	6	1	3	1	4	7	10	8	8	7	5	9	1	1	4	1	0	0	0	0	0	0	140
1905–6:																																	
50-bird pens	20	2	3	2	2	3	6	5	2	3	4	4	8	4	8	11	9	12	12	12	5	12	14	10	5	0	0	0	0	0	0	0	178
100-bird pens	13	11	5	4	3	4	6	3	3	5	4	7	6	6	4	7	8	17	8	13	8	11	12	6	5	3	0	0	0	0	0	0	182
150-bird pens	46	15	6	6	2	5	3	5	4	5	5	7	10	12	7	10	11	12	9	14	25	19	15	12	5	2	3	0	0	0	0	0	275
1906–7:																																	
50-bird pens	81	10	3	5	7	5	6	4	5	7	5	6	6	4	6	5	3	2	6	4	2	3	0	2	0	0	0	0	0	0	0	0	187
100-bird pens	96	12	9	5	9	3	4	2	5	3	5	3	1	1	4	3	3	0	4	6	1	1	2	2	1	0	0	0	0	0	0	0	185
150-bird pens	136	13	22	16	6	1	6	8	7	9	4	5	1	5	4	4	5	4	10	1	5	0	7	0	0	1	0	1	0	0	0	0	281
Total birds	654	107	71	65	59	48	64	49	55	60	70	52	62	72	72	85	89	91	94	97	94	108	90	49	29	13	5	3	0	0	0	0	2.407

Laying year.	Number of hens laying number of eggs designated in box head.																													Total hens.
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
1899–1900	10	2	4	3	1	2	0	6	3	2	3	4	1	2	5	4	4	4	3	2	1	3	1	0	0	0	0	0	0	70
1900–1901	0	2	3	0	2	4	2	3	1	5	2	3	2	2	2	10	7	4	6	4	6	8	5	0	2	0	0	0	0	85
1901–2	3	0	1	3	1	1	2	1	1	3	3	1	6	1	1	5	4	2	2	5	1	0	1	0	0	0	0	0	0	48
1902–3	24	11	2	1	3	2	3	9	9	4	5	10	10	7	7	7	6	6	5	7	5	2	1	0	0	0	1	0	0	147
1903–4	28	4	2	5	5	9	7	14	7	4	9	6	9	10	17	19	16	13	16	11	22	7	7	5	1	1	0	0	0	254
1904–5:																														
50-bird pens	15	6	6	7	4	8	4	9	10	13	6	7	4	10	15	18	20	25	32	14	22	10	12	4	2	0	0	0	0	283
100-bird pens	6	3	1	3	2	5	4	4	3	3	4	4	7	2	11	3	3	4	8	6	5	1	0	0	0	0	0	0	0	92
150-bird pens	24	5	4	3	8	7	8	7	3	6	10	1	1	3	7	6	10	5	10	6	5	0	1	0	0	0	0	0	0	140
1905–6:																														
50-bird pens	1	5	5	2	2	3	4	4	5	1	8	7	7	7	8	7	22	15	16	20	11	14	1	3	0	0	0	0	0	178
100-bird pens	11	3	4	3	4	6	5	3	5	4	7	7	8	6	9	6	12	13	16	18	17	8	6	0	1	0	0	0	0	182
150-bird pens	20	13	10	12	7	9	8	8	8	6	6	4	13	11	15	14	25	21	22	17	11	12	3	0	0	0	0	0	0	275
1906–7:																														
50-bird pens	23	5	4	3	7	9	6	4	11	5	13	8	12	7	8	8	11	10	14	6	6	3	3	0	1	0	0	0	0	187
100-bird pens	71	10	8	10	12	6	5	9	5	5	6	5	3	1	6	4	8	2	2	4	1	1	0	1	0	0	0	0	0	185
150-bird pens	86	17	14	10	10	13	11	9	7	5	11	6	11	6	5	12	10	11	10	6	6	3	0	1	1	0	0	0	0	281
Total birds	322	86	68	65	68	84	69	90	78	66	93	73	94	75	116	123	158	135	162	126	119	72	41	14	8	1	1	0	0	2,407

TABLE V.—*Frequency distribution of egg production for the month of March.*

Laying year.	Number of hens laying number of eggs designated in box head.																																Total hens.
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1899–1900	2	1	1	1	2	0	3	3	2	4	3	5	4	5	3	4	7	3	3	3	4	2	4	0	1	0	0	0	0	0	0	0	70
1900–1901	0	1	0	0	1	2	2	2	5	2	0	2	3	3	1	3	5	5	5	6	9	5	6	6	4	2	3	2	0	0	0	0	85
1901–2	0	0	0	0	0	0	0	1	0	3	1	1	4	3	4	1	3	1	3	5	5	3	4	1	3	1	1	0	0	0	0	0	48
1902–3	5	1	0	0	2	4	0	5	3	2	6	10	10	8	8	5	13	11	14	10	2	8	6	4	7	3	0	0	0	0	0	0	147
1903–4	12	2	0	1	2	1	3	2	2	4	7	10	7	10	8	15	9	8	17	14	19	13	32	23	18	10	3	1	1	0	0	0	254
1904–5:																																	
50-bird pens	6	0	1	1	0	1	1	3	8	3	6	7	15	11	11	13	10	17	15	12	23	28	19	28	22	14	3	3	2	0	0	0	283
100-bird pens	2	1	1	2	4	3	3	2	6	10	4	8	5	3	4	7	4	4	2	3	6	2	2	2	1	0	1	0	0	0	0	0	92
150-bird pens	16	4	2	5	0	0	3	8	6	6	8	9	5	3	4	7	5	8	4	16	4	9	3	3	1	1	0	0	0	0	0	0	140
1905–6:																																	
50-bird pens	0	0	2	2	0	2	0	2	2	3	3	3	6	2	9	7	11	9	13	15	16	20	15	13	12	7	2	2	0	0	0	0	178
100-bird pens	2	4	0	2	3	0	2	0	3	1	6	6	3	7	3	9	15	10	14	12	16	16	19	14	7	5	3	0	0	0	0	0	182
150-bird pens	3	0	0	1	0	2	1	4	7	8	4	8	11	12	14	11	17	27	18	38	19	16	23	16	14	1	0	0	0	0	0	0	275
1906–7:																																	
50-bird pens	3	1	0	2	4	3	0	2	3	5	2	3	8	6	4	3	10	8	7	18	25	16	18	16	11	3	4	0	1	1	0	0	187
100-bird pens	7	3	2	1	3	6	2	4	7	10	5	8	9	10	16	7	11	15	12	15	8	2	9	7	3	3	0	0	0	0	0	0	185
150-bird pens	10	6	4	1	5	5	5	6	10	8	8	14	19	15	12	11	12	24	16	11	15	18	18	14	7	4	2	0	1	0	0	0	281
Total birds	68	24	13	19	26	29	25	44	64	69	63	94	109	98	101	103	132	150	143	178	171	158	178	147	111	54	22	8	5	1	0	0	2,407

TABLE VI.—*Frequency distribution of egg production for the month of April.*

Laying year.	Number of hens laying number of eggs designated in box head.																															Total hens.
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1899–1900	2	0	1	0	0	2	0	1	1	0	2	4	1	3	5	4	4	9	3	4	10	8	3	0	2	1	0	0	0	0	0	70
1900–1901	2	0	0	1	0	0	0	1	2	0	0	3	3	5	5	4	6	2	2	8	8	7	6	6	7	4	2	0	1	0	0	85
1901–2	0	0	1	0	0	0	1	0	0	0	2	3	1	0	1	2	1	2	5	5	4	5	4	5	3	2	1	0	0	0	0	48
1902–3	2	1	0	0	2	3	1	1	2	4	2	5	5	3	4	5	5	10	11	12	14	16	8	11	14	4	1	1	0	0	0	147
1903–4	10	3	2	1	1	2	3	3	2	5	14	13	15	14	21	23	26	18	13	12	8	16	10	12	5	2	0	0	0	0	0	254
1904–5:																																
50-bird pens	10	4	0	5	0	3	3	5	4	8	6	9	15	18	15	12	25	21	20	23	23	19	13	8	6	3	2	2	1	0	0	283
100-bird pens	2	1	2	2	0	1	1	2	0	4	1	0	5	6	4	5	6	10	7	8	6	8	2	4	3	0	2	0	0	0	0	92
150-bird pens	5	8	5	2	0	2	1	5	0	7	8	6	7	5	8	9	9	8	9	17	8	6	3	2	0	0	0	0	0	0	0	140
1905–6:																																
50-bird pens	1	0	1	0	4	1	0	0	3	2	7	4	5	9	15	16	14	15	15	16	12	14	16	5	2	1	0	0	0	0	0	178
100-bird pens	4	0	1	2	1	2	2	2	2	6	7	7	8	13	12	18	11	19	24	10	12	11	4	2	0	1	1	0	0	0	0	182
150-bird pens	1	1	1	5	2	4	6	5	5	5	7	5	21	15	24	28	18	29	17	20	21	19	9	4	2	0	1	0	0	0	0	275
1906–7:																																
50-bird pens	4	1	1	0	2	1	1	1	2	4	7	4	8	11	6	11	9	11	20	5	20	8	17	17	6	6	3	1	0	0	0	187
100-bird pens	4	2	0	1	1	1	2	4	0	6	7	3	8	8	11	11	14	10	17	17	14	9	13	9	8	3	1	0	1	0	0	185
0-bird pens	8	8	1	0	5	1	4	3	5	7	6	13	17	15	19	20	14	22	22	14	24	18	16	10	5	2	1	1	0	0	0	281
Total birds	55	29	16	19	18	23	25	33	28	58	76	79	119	125	150	168	162	186	185	171	184	164	124	95	63	29	15	5	3	0	0	2,407

TABLE VII.—*Frequency distribution of egg production for the month of May.*

Laying year.	Number of hens laying number of eggs designated in box head.																																Total hens.
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1899–1900	1	1	0	0	1	2	1	0	2	1	4	7	3	3	3	2	6	6	7	2	4	2	6	2	2	2	0	0	0	0	0	0	70
1900–1901	3	2	1	0	0	0	2	1	2	2	3	2	3	5	11	3	6	5	1	5	9	3	5	7	4	0	0	0	0	0	0	0	85
1901–2	1	0	2	0	0	1	0	1	0	0	2	3	0	3	1	3	5	3	4	5	2	2	4	2	1	3	0	0	0	0	0	0	48
1902–3	3	1	0	1	0	1	1	1	2	0	4	11	4	11	4	11	10	5	12	7	9	13	13	7	7	5	4	0	0	0	0	0	147
1903–4	14	5	6	2	7	3	7	5	9	17	16	24	24	15	24	18	13	13	6	10	4	6	2	1	2	0	1	0	0	0	0	0	254
1904–5:																																	
50-bird pens	19	9	1	3	2	2	7	4	7	11	14	17	10	23	23	12	12	16	11	16	19	17	5	6	5	4	3	2	1	1	0	1	283
100-bird pens	2	3	2	0	0	1	0	1	2	5	4	6	4	6	9	8	4	5	4	6	6	5	5	3	1	0	0	0	0	0	0	0	92
150-bird pens	17	4	2	3	2	2	4	5	7	2	7	7	2	12	7	8	3	8	8	12	4	3	4	1	2	2	1	1	0	0	0	0	140
1905–6:																																	
50-bird pens	2	3	4	4	7	9	3	11	13	4	12	17	14	13	11	13	7	8	7	3	5	3	2	2	0	1	0	0	0	0	0	0	178
100-bird pens	13	3	5	4	5	5	9	4	13	9	9	13	21	14	8	11	9	5	3	6	4	4	3	2	0	0	0	0	0	0	0	0	182
150-bird pens	14	11	5	4	9	11	10	11	19	16	17	21	20	20	12	20	13	14	10	5	4	3	1	1	2	1	1	0	0	0	0	0	275
1906–7:																																	
50-bird pens	6	4	2	1	4	0	3	3	7	5	12	9	12	13	13	6	9	11	15	6	9	9	13	8	2	5	0	0	0	0	0	0	187
100-bird pens	6	1	2	1	4	2	2	3	3	5	5	10	9	4	13	14	14	17	14	11	8	14	7	8	4	0	1	2	1	0	0	0	185
150-bird pens	17	3	1	0	1	8	6	8	14	14	17	23	23	16	17	21	10	14	9	14	15	9	8	10	1	2	0	0	0	0	0	0	281
Total birds	118	50	33	23	42	47	55	58	100	91	126	170	149	158	156	150	121	130	111	108	102	93	78	60	33	25	11	5	2	1	0	1	2,407

TABLE VIII.—*Frequency distribution of egg production for the month of June.*

Laying year.	Number of hens laying number of eggs designated in box head.																															Total hens.
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1899–1900	4	1	2	3	2	1	0	1	1	5	1	4	4	4	7	9	6	1	2	3	4	0	2	1	1	0	1	0	0	0	0	70
1900–1901	7	1	0	1	0	0	1	1	2	5	6	8	1	2	3	2	7	6	5	4	4	8	6	2	1	1	0	1	0	0	0	85
1901–2	0	0	0	0	0	0	0	0	1	2	1	1	0	6	3	5	5	0	5	3	7	4	1	2	1	1	0	0	0	0	0	48
1902–3	6	0	2	2	0	2	0	0	2	5	4	8	7	7	8	8	9	7	9	12	13	14	11	6	2	2	1	0	0	0	0	147
1903–4	22	4	3	3	2	2	3	7	5	10	20	22	25	23	18	16	11	9	7	9	9	7	5	5	3	4	0	0	0	0	0	254
1904–5:																																
50-bird pens	25	5	2	1	7	1	13	2	10	13	12	18	19	18	22	21	14	16	9	10	17	8	9	5	1	0	3	1	1	0	0	283
100-bird pens	4	1	2	3	1	2	0	5	3	3	3	7	7	3	7	4	7	3	7	0	7	4	4	2	1	0	1	0	1	0	0	92
150-bird pens	28	7	1	2	3	3	2	3	5	4	6	12	6	5	9	6	5	7	4	7	2	4	5	3	0	0	0	0	1	0	0	140
1905–6:																																
50-bird pens	2	1	1	0	3	1	4	4	14	6	10	12	20	15	11	7	18	12	9	6	7	8	5	1	0	1	0	0	0	0	0	178
100-bird pens	7	4	6	0	2	3	4	2	8	7	17	15	15	9	13	10	9	9	6	9	10	8	2	4	1	1	1	0	0	0	0	182
150-bird pens	18	5	2	4	4	6	7	11	15	14	20	16	26	17	24	15	17	18	5	11	9	4	2	4	0	0	1	0	0	0	0	275
1906–7:																																
50-bird pens	14	6	3	2	6	4	3	10	13	11	9	14	14	10	7	13	12	5	8	8	3	6	3	3	0	0	0	0	0	0	0	187
100-bird pens	11	2	3	3	3	1	4	3	5	6	7	11	15	17	14	16	12	11	7	4	11	9	1	5	3	1	0	0	0	0	0	185
150-bird pens	45	7	3	3	1	5	4	5	16	17	13	24	22	15	15	13	19	12	14	11	4	6	4	1	2	0	0	0	0	0	0	281
Total birds	193	44	30	27	34	31	45	54	100	108	129	172	181	151	161	145	151	116	97	97	107	90	60	44	16	11	8	2	3	0	0	2,407

TABLE IX.—*Frequency distribution of egg production for the month of July.*

Laying year.	Number of hens laying number of eggs designated in box head.																																Total hens.
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1899–1900	7	0	1	0	0	1	0	2	4	4	5	5	7	4	7	7	4	3	1	2	2	2	1	0	0	1	0	0	0	0	0	0	70
1900–1901	8	0	2	0	0	0	2	3	4	3	4	3	0	9	6	4	9	7	6	4	5	0	1	0	4	1	0	0	0	0	0	0	85
1901–2	2	1	0	2	0	1	0	0	0	2	1	2	0	2	5	3	8	2	3	1	4	5	1	2	1	0	0	0	0	0	0	0	48
1902–3	2	0	2	3	1	3	4	2	1	5	6	2	5	9	14	12	9	10	8	8	7	7	8	12	0	2	4	1	0	0	0	0	147
1903–4	28	5	5	3	7	6	7	5	15	14	20	25	32	19	18	7	11	5	5	3	4	3	1	2	1	3	0	0	0	0	0	0	254
1904–5:																																	
50-bird pens	39	6	7	1	7	5	7	6	8	15	15	18	22	26	15	15	11	15	13	10	4	11	1	2	2	1	1	0	0	0	0	0	283
100-bird pens	16	1	2	0	0	1	2	1	3	2	7	5	5	5	5	7	4	5	5	5	3	1	3	2	2	0	0	0	0	0	0	0	92
150-bird pens	36	5	1	2	0	2	3	5	6	5	6	6	8	11	3	1	5	7	5	5	6	1	3	3	4	0	0	1	0	0	0	0	140
1905–6:																																	
50-bird pens	12	2	2	3	4	3	12	14	9	7	15	19	13	17	9	6	8	5	7	3	2	4	1	1	0	0	0	0	0	0	0	0	178
100-bird pens	20	6	6	4	4	7	8	9	12	8	11	13	10	13	9	6	11	4	2	5	4	7	2	0	0	0	0	1	0	0	0	0	182
150-bird pens	47	7	3	2	7	13	11	16	20	13	17	17	21	16	12	11	8	9	6	5	4	5	1	4	0	0	0	0	0	0	0	0	275
1906–7:																																	
50-bird pens	14	6	0	0	3	3	4	4	8	8	13	19	12	13	13	13	8	6	7	12	4	5	5	3	3	1	0	0	0	0	0	0	187
100-bird pens	17	3	2	2	6	6	3	6	4	18	15	11	14	10	11	8	8	8	4	7	4	7	4	1	2	2	1	0	1	0	0	0	185
150-bird pens	49	6	2	5	3	4	2	13	16	21	22	23	15	13	17	19	5	9	9	9	7	1	4	3	1	0	0	1	0	0	0	2	281
Total birds	297	48	35	27	42	55	65	86	110	125	157	168	164	167	144	119	109	95	81	79	60	59	36	35	20	11	6	4	1	0	0	2	2,407

TABLE X.—*Frequency distribution of egg production for the month of August.*

Laying year.	Number of hens laying number of eggs designated in box head.																																Total hens.
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1899–1900	9	1	0	1	1	1	0	3	3	4	2	7	6	7	2	2	4	6	0	1	3	5	0	2	0	0	0	0	0	0	0	0	70
1900–1901	11	2	2	2	1	1	0	4	5	6	2	0	4	4	2	9	5	7	4	5	2	3	0	2	1	0	1	0	0	0	0	0	85
1901–2	4	0	0	1	1	2	0	3	0	2	1	3	2	3	4	2	3	3	1	1	8	2	0	1	0	1	0	0	0	0	0	0	48
1902–3	13	9	0	6	1	1	3	2	5	5	6	8	7	9	6	8	7	7	9	7	6	7	5	4	4	0	2	0	0	0	0	0	147
1903–4	41	6	3	4	2	7	4	6	15	9	24	16	29	15	14	17	5	8	9	5	3	3	4	2	1	2	0	0	0	0	0	0	254
1904–5:																																	
50-bird pens	46	10	6	2	1	5	5	8	14	8	18	18	15	17	17	17	15	17	10	14	9	2	4	2	0	3	0	0	0	0	0	0	283
100-bird pens	15	4	1	2	0	1	1	1	4	2	6	8	8	7	3	4	7	3	2	4	1	4	1	1	2	0	0	0	0	0	0	0	92
150-bird pens	41	4	2	3	1	1	4	6	6	5	7	8	8	11	10	5	5	1	3	4	1	1	0	3	0	0	0	0	0	0	0	0	140
1905–6:																																	
50-bird pens	19	5	3	4	4	7	9	11	12	13	13	20	12	6	7	5	6	8	5	4	2	1	0	2	0	0	0	0	0	0	0	0	178
100-bird pens	29	18	5	7	8	11	16	10	4	7	13	13	7	7	8	3	5	5	8	0	2	0	0	1	0	0	0	0	0	0	0	0	182
150-bird pens	59	22	15	10	11	19	18	7	11	12	16	8	9	12	11	11	6	3	5	4	4	2	0	0	0	0	0	0	0	0	0	0	275
1906–7:																																	
50-bird pens	10	4	2	1	3	5	4	9	8	10	13	13	15	16	17	19	7	4	11	4	3	3	2	4	0	0	0	0	0	0	0	0	187
100-bird pens	14	8	3	4	7	2	3	4	8	5	10	20	10	12	10	13	11	5	8	7	4	3	4	7	1	1	0	0	1	0	0	0	185
150-bird pens	34	16	11	8	12	5	10	8	8	17	20	27	19	16	19	8	8	7	5	7	5	4	1	4	2	0	0	0	0	0	0	0	281
Total birds	345	109	53	55	53	68	77	82	103	105	151	169	151	142	130	123	94	84	75	67	53	40	21	35	11	7	3	0	1	0	0	0	2,407

TABLE XI.—*Frequency distribution of egg production for the month of September.*

Laying year.	Number of hens laying number of eggs designated in box head.																															Total hens.
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1899–1900	14	1	2	1	1	1	2	2	6	2	4	6	4	5	4	2	3	1	3	4	0	2	0	0	0	0	0	0	0	0	0	70
1900–1901	14	1	4	2	2	3	4	0	5	2	3	4	6	4	1	7	2	5	2	3	2	6	3	0	0	0	0	0	0	0	0	85
1901–2	13	1	2	1	0	1	1	4	1	1	0	1	3	1	2	2	3	1	2	3	2	1	1	1	0	0	0	0	0	0	0	48
1902–3	24	3	5	2	5	5	6	7	3	5	5	5	6	9	4	6	4	7	9	9	7	7	1	2	0	1	0	0	0	0	0	147
1903–4	43	7	5	3	2	15	7	8	10	7	18	17	20	12	10	17	5	11	6	10	6	8	3	1	3	0	0	0	0	0	0	254
1904–5:																																
50-bird pens	60	8	2	2	3	5	3	8	9	13	17	17	9	14	13	11	10	12	13	8	8	17	10	6	1	3	1	0	0	0	0	283
100-bird pens	22	1	0	0	2	2	4	4	1	5	5	1	3	4	2	7	5	4	3	1	6	1	3	3	2	0	1	0	0	0	0	92
150-bird pens	49	3	2	4	4	3	2	6	4	7	3	7	6	8	7	2	3	6	0	3	4	3	3	1	0	0	0	0	0	0	0	140
1905–6:																																
50-bird pens	23	6	7	4	8	5	8	7	11	10	5	5	11	7	11	8	8	11	7	7	5	1	1	1	0	0	1	0	0	0	0	178
100-bird pens	44	15	8	4	4	7	9	6	6	8	6	11	5	10	7	6	5	4	4	6	2	3	2	0	0	0	0	0	0	0	0	182
150-bird pens	76	22	9	11	8	13	10	12	13	11	9	7	8	15	6	2	11	10	5	8	4	2	2	1	0	0	0	0	0	0	0	275
1906–7:																																
50-bird pens	56	22	11	8	10	11	15	7	11	6	2	9	4	2	2	3	4	2	1	0	1	0	0	0	0	0	0	0	0	0	0	187
100-bird pens	26	16	11	11	4	9	5	10	13	8	10	8	8	4	8	3	4	9	5	3	2	3	5	0	0	0	0	0	0	0	0	185
150-bird pens	90	41	18	11	16	9	15	14	7	4	6	2	6	10	9	3	4	9	1	2	2	1	0	1	0	0	0	0	0	0	0	281
Total birds	554	147	86	64	69	89	91	95	100	89	93	100	99	105	86	79	71	92	61	67	51	55	34	17	6	4	3	0	0	0	0	2,407

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A BIOMETRICAL STUDY OF EGG PRODUCTION IN THE DOMESTIC FOWL.

III. VARIATION AND CORRELATION IN THE PHYSICAL CHARACTERS OF THE EGG.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
Washington, D. C., December 23, 1913.

Sir: I have the honor to transmit herewith, for publication as Part III of Bulletin 110 of this bureau, the third paper in the series under the general title "A Biometrical Study of Egg Production in the Domestic Fowl," this paper being entitled "Variation and Correlation in the Physical Characters of the Egg," by Drs. Raymond Pearl and Frank M. Surface, of the Maine Agricultural Experiment Station.

Respectfully,

A. D. Melvin,
Chief of Bureau.

Hon. D. F. Houston,
Secretary of Agriculture.

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A BIOMETRICAL STUDY OF EGG PRODUCTION IN THE DOMESTIC FOWL.

III. VARIATION AND CORRELATION IN THE PHYSICAL CHARACTERS OF THE EGG.[1]

INTRODUCTION.

In the previous parts[2] of this bulletin attention has been directed primarily toward the statistical or mass phenomena of egg production. To reach anything approaching an adequate understanding of those phenomena it is essential that the production of an egg be analyzed as a physiological process pertaining to the individual. Such physiological studies[3] have been carried on concurrently with this "Biometrical Study."

The formation and deposition of a bird's egg involve a large series of complex processes. In order to get a better understanding of the exact bearing of this paper on the general problem it may be useful to enumerate a few of the more evident of these processes as follows: (1) The development of the ovary into the laying condition and its effect upon the somatic characters of the bird. (2) The accompanying increase in size and functional activity of the oviduct. (3) The growth of the oocyte and the elaboration of the yolk. (4) The rupture of the ovarian follicle (ovulation). (5) The inclusion of the yolk by the funnel of the oviduct. (6) The movement of the yolk down the oviduct. (7) The secretion of the albumen. (8) The formation of the shell membranes. (9) The secretion of the calcareous shell. (10) The determination of the characteristic shape and color of the shell. (11) The several processes involved in the extrusion of the egg.

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[1] Papers from the Biological Laboratory of the Maine Agricultural Experiment Station, No. 45.

[2] A Biometrical Study of Egg Production in the Domestic Fowl. I. Variation in Annual Egg Production. U. S. Department of Agriculture, Bureau of Animal Industry, Bulletin 110, pp. 1-80, 1909. II. Seasonal Distribution of Egg Production. *Ibid.*, pp. 81-170, 1911.

[3] The results of these studies to date have been published in the following series of papers under the general title "Studies on the Physiology of Reproduction in the Domestic Fowl:"

I. Regulation in the morphogenetic activity of the oviduct. Jour. Exp. Zool., vol. 6, pp. 339-359, 1909.

II. Data on the inheritance of fecundity obtained from the records of egg production of the daughters of "200-egg" hens. Maine Agricultural Experiment Station, Annual Report for 1909, pp. 49-84.

III. A case of incomplete hermaphroditism. Biological Bulletin, vol. 17, pp. 271-286, 1909.

IV. Data on certain factors influencing the fertility and hatching of eggs. Maine Agricultural Experiment Station, Annual Report for 1909, pp. 105-164.

V. Data regarding the physiology of the oviduct. Jour. Exp. Zool., vol. 12, pp. 99-132, 1912.

Very little definite information regarding these various processes is to be found in the existing literature. The problem is a complex one and needs to be attacked from various standpoints. The essential facts regarding the physical characters of the normal hen's egg and the variation and correlation of these characters are fundamental data necessary for the most successful prosecution of experimental work on the problems of egg production. To supply these data is the purpose of the present paper.

We shall in this part of the study deal with the "product" phase of egg production. Quality and character of product are as essential as quantity in egg production, when the matter is looked at from the economic standpoint. In recent years increasing attention has been paid to the study of factors influencing the character and quality of eggs. Foremost in economic importance are the investigations dealing with the effect of the environmental vicissitudes to which the egg is subjected in the process of getting from the hen to the breakfast egg cup. Here may be mentioned the recent studies of Lamon and Opperman.[1] The bacteriology and chemistry of the egg are also receiving attention. In such studies as those of Pennington[2] and Willard and Shaw[3] the factors dealt with as influencing the quality and character of eggs are innate, in that they are determined by the hen in greater or less degree. Finally, however, beyond all these are the essentially innate biological factors which influence the character of eggs. The size, shape, and color of the egg are not determined by the way in which it is handled in getting to market. They are basic biological characters, which are presumably inherited. Also such qualities as texture of shell, thickness of shell, color of yolk and albumen, etc., are characteristics which depend for their precise determination on the physiological economy of the hen. But these qualities are not without economic significance. There are definite, if not as yet altogether precisely defined, market standards with regard to each of these characteristics which have been enumerated. The producer wants to put on the market an egg which will meet these standards. It is important that there be as clear an understanding and complete a knowledge as can be obtained of the underlying biological factors involved. The present study is intended as a contribution in this direction.

This Part III deals with the shape and size of eggs laid by "purebred" domestic fowls. There is good reason to believe that the final shape of an egg is determined in the lower portion of the oviduct known as the uterus or shell gland. The evidence for this conclusion has been stated in a previous paper[1] by one of the writers and need not be repeated in detail here. It was there pointed out that there are two possibilities with regard to the mechanism by which the shape is determined. These are (a) the active contractions of the muscular walls of the uterus and (b) the passive elasticity of these walls, causing them to act as a mold for the plastic egg mass. From a careful study of the successive eggs of an individual hen it was concluded that the finer and individual form characteristics of eggs were determined by muscular contractions before and during the deposition of the calcareous shell. It is only in this way that one can account for the changes undergone by successive eggs of the same individual. Hence the shape of an egg measures in an indirect way the physiological activity of the muscles in one portion of the oviduct.

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[1] Lamon, H. M., and Opperman, C. L. The improvement of the farm egg. U. S. Dept. Agr., Bur. Anim. Ind., Bulletin 141, pp. 1-43, 1911.

[2] Pennington, M. E. A chemical and bacteriological study of fresh eggs. Jour. Biol. Chem., vol. 7, pp. 109-132, 1909.

[3] Willard, J. T., and Shaw, R. H. Analysis of eggs. Kansas Agr. Expt. Sta., Bulletin 159, pp. 143-177, 1909.

The volume and weight—i. e., the size—of an egg are determined both by the size of the yolk elaborated before it leaves the ovary and by the amount of albumen secreted by the oviduct. In studying the variation in the size and volume of eggs we are indirectly studying the variation of certain physiological processes. These processes, connected with the formation of the yolk and albumen, are among the most important factors in egg production. Whatever light may be thrown upon them can not but aid in an ultimate understanding of the physiology of egg formation.

The ordinary concept of an egg is of a structure of fairly definite shape and size. This is reflected in such common expressions as "egg-shaped" and "the size of an egg." Nevertheless every poultryman knows that the size of eggs varies greatly—most markedly between different breeds of poultry. But within the same breed the variation is often scarcely less striking. The limits of this variability may extend, on the one hand, to the very small eggs occasionally found with a small amount of albumen and no yolk, or a very small amount without definite yolk membrane. On the other hand, a hen may occasionally lay an enormous double or triple yolked egg. It is not the purpose of this paper to deal with either these abnormally small or abnormally large eggs.

There is, however, a variation in the physical characters of what may be called normal eggs, as distinguished from such abnormal specimens as have just been mentioned. A "normal" egg may be regarded as one in which a single yolk surrounded by a yolk membrane is inclosed within the usual layers of albumen, shell membrane, and calcareous shell. It is with such normal eggs that the present investigation is concerned.

Among the general topics dealt with in this part of the study the following are the more important. The specific problems which arise in connection with these topics will, in order to avoid repetition, only be stated and discussed in the sections of the paper wherein the data bearing upon them are presented.

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[1] Pearl, R. Regulation in the morphogenetic activity of the oviduct. Jour. Exp. Zool., vol. 6, pp. 339–359, 1909.

1. The mean size and variability of the various physical characters of eggs from different individuals.
2. The nature of the frequency distributions to which measurements of these characters lead.
3. The correlation between the several physical characters of the egg.
4. The regression of the several characters upon one another, and the characteristic equations deduced from the regression constants, together with the use of such characteristic equations in predicting the probable condition of one character of the egg from a knowledge of the actual condition of other characters.
5. Comparison of the eggs of the domestic fowl with those of wild species of birds.
6. The degree of variation (or uniformity) exhibited in the eggs laid by an individual bird, and the relation of the variation in the product of an individual to variation in the eggs of the race (flock or strain).

MATERIAL AND METHODS.

The material upon which this paper is based consists of several series of egg measurements. These were obtained from eggs laid at the poultry plant of the Maine Agricultural Experiment Station during the years 1908 and 1909. Except when a specific statement to the contrary is made, all discussions in this paper refer to the data from the eggs of Barred Plymouth Rock pullets. The strain of Barred Plymouth Rocks from which these eggs came has been bred at the Maine Station since 1898.[1] Previous to that time they had been bred for a number of years by the late Prof. G. M. Gowell. They are pure-bred birds in the fancier's sense. The birds have been fed and cared for under conditions as nearly uniform as could be obtained. Hence the material with which we have to do is as nearly homogeneous as it is practically possible to obtain. This paper is based upon the measurement of about 5,500 eggs. It is believed that there are sufficient data in the various series to establish with considerable accuracy the constants derived from them for normal eggs of Barred Plymouth Rock pullets.

In each of the series of data here considered the length and maximum breadth of each egg were measured. From these two measurements there were calculated in most cases (*a*) the length-breadth index and (*b*) the bulk or volume of the egg. In addition to these data the weight of the fresh egg was obtained in series A.

The length and breadth of the eggs were measured with the aid of a large micrometer caliper provided with a ratchet head. This caliper was held in a wooden frame so to avoid the expansion and contraction due to the varying conditions of temperature which would be induced by handling. The ratchet head insures that the same pressure is exerted on each egg by the caliper jaws when the reading is taken. The measurements were recorded to hundredths of a millimeter. In cases where an egg was not perfectly symmetrical the largest diameter was taken. It not infrequently happened in the measurement of the breadth that one diameter was found to be larger than the others. In such cases the egg was turned until this diameter was found and its magnitude recorded.

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[1] For a discussion of the breeding of this flock see Part I of this study.

The length-breadth index was obtained by dividing one hundred times the breadth by the length. This constant gives a measure of the shape of the egg. A long and narrow egg will have a relatively low index, while a short and broad egg will have a high index. Its value is independent of the absolute size of the egg except in so far as the length is correlated with the breadth. This correlation is very small.

In determining the volume or bulk, as it will be called here, the egg was regarded as a perfect prolate spheroid, and the formula for obtaining the volume of such a body was employed. This formula is:

$$V=\frac{4}{3}\pi\, a^2b$$

where V denotes volume, and a and b are the semi-axes, a being the shorter. As actually used on eggs this formula becomes:

$$V_{egg}=4.1888\ (\tfrac{1}{2}\text{ breadth})^2\times(\tfrac{1}{2}\text{ length}).$$

The bulk gives us a measure which should bear a definite relation to the weight if the specific gravity of an egg is constant. In calculating both the index and bulk, the length and breadth measurements were used to the second decimal place. All of the weights used in this paper were obtained on balances sensitive to tenths of a milligram and the weights recorded to the nearest milligram.

In series A a determination of the color of each egg was made. As is well known, Barred Plymouth Rocks lay tinted eggs. The colors are, however, so delicate that their measurement offers special difficulties. After studying the matter carefully the following procedure was decided upon: To form a series of egg shells which should represent as nearly as possible equidistant steps in a graded series leading from the lightest egg anywhere to be found, on one end, to the darkest eggs which occur, on the other; then, having obtained such a "normal" series, to compare with the series each egg whose color it was desired to record, and note (by number) the "normal" egg with which it agreed in color, or the two members of the series between which it fell in case it exactly agreed with no single one. In attempting to follow this procedure in practice the first difficulty encountered was that more than one color series was found to exist in Barred Plymouth Rock eggs. Tinted hens' eggs are usually called "brown" eggs. As a matter of fact many of them are not brown at all but a delicate shade of pink. After handling hundreds of eggs with this point in mind we found it necessary to form three normal color scales instead of one as originally contemplated. These three series were designated in our records respectively as the "brown," "brown-pink," and "pink" series of comparison egg shells. The brown series included all eggs which showed no trace whatever of a reddish or pink pigment. The pink series included only eggs which showed no trace of a brown color. Finally the "brown-pink" included eggs intermediate in color, showing evidence of both the brown and the red pigments. From 10 to 14 eggs were included in each of these three normal series and numbered from 1 (the lightest egg in the series) up to whatever the number of the final (darkest) egg in the series might be. Each individual egg in series A was then compared (always by the same person, R. P.) with these series, and recorded. Discussion of these color measurements is deferred for the present, pending the collection of further and more adequate data.

The following is a description of the series of measurements which furnish the chief data for this paper:

Series A.—This consists of the determination of the length, breadth, and weight, the calculated index and bulk, and the color of 450 eggs. These eggs were all laid on the same day (Feb. 12, 1908), and consequently no two eggs were laid by the same hen. Each egg measured is from a different hen. They give the fundamental data on *inter-individual* or racial variation in Barred Plymouth Rock eggs. All the eggs were from pullets of approximately the same age, having been hatched in April and May, 1907. The detailed measurements for this series are given in Appendix III, Table I.

Series B.—This series contains the data for *intra-individual* variations in eggs. It consists of the measurements of the length and breadth of 25 eggs from each of 100 birds. The measurements were made during April and May, 1908. These eggs were likewise all obtained from pullets approximately 1 year old. The eggs were taken from those pullets which were in the breeding pens and the eggs measured before being put into the incubators. No selection with regard to egg characters of the pullets in the breeding pens was practiced in choosing the birds whose eggs were to be measured in this series. There is no reason to doubt that these 100 hens represent a random sample of the flock in respect to egg characters.

The statistical data obtained in the manner described were subjected to biometrical analysis. For a description of the technical methods used in this field of work the reader is referred to the original papers by Pearson and his associates in the Philosophical Transactions of the Royal Society and in Biometrika.[1] A useful condensed account of many of the methods is given by Elderton.[2]

Great care has been exercised in performing the various calculations. As many as possible of the fundamental constants have been worked twice independently. It is hoped that the paper is as free of arithmetical errors as is possible in so extensive a piece of work.

VARIATION OF THE BARRED PLYMOUTH ROCK EGG IN SIZE AND SHAPE.

The fundamental data for this section of the paper are contained in series A. It will be recalled that this series consists of the measurement of 450 eggs from as many different pullets. During the year in which these measurements were made there were 850 pullets in the houses. Every egg laid on February 12, 1908, with the exception of a few cracked ones, was used in this series. Consequently these 450 eggs constitute a random sample of the flock. The frequency distributions for size and shape of eggs are found in the correlation tables on pages 191–194. In order to present the variation data in a more compact form Table 1 has been prepared.

TABLE 1.—*Frequency distributions of variation in the size and shape of eggs.*

Length.		Breadth.		Shape index.		Bulk.		Weight.	
Millimeters.	Frequency.	Millimeters.	Frequency.	Per cent.	Frequency.	Cubic centimeters.	Frequency.	Grams.	Frequency.
49.0–49.9	1	38.0–38.4	2	60.0–60.9	1	40.0–40.9	1	42.0–42.9	1
50.0–50.9	1	38.5–38.9	4	61.0–61.9	1	41.0–41.9	1	43.0–43.9	1
51.0–51.9	7	39.0–39.4	9	62.0–62.9	2	42.0–42.9	2	44.0–44.9	0
52.0–52.9	22	39.5–39.9	18	63.0–63.9	1	43.0–43.9	6	45.0–45.9	3
53.0–53.9	36	40.0–40.4	41	64.0–64.9	3	44.0–44.9	5	46.0–46.9	6
54.0–54.9	71	40.5–40.9	52	65.0–65.9	3	45.0–45.9	15	47.0–47.9	10
55.0–55.9	68	41.0–41.4	41	66.0–66.9	5	46.0–46.9	25	48.0–48.9	17
56.0–56.9	77	41.5–41.9	65	67.0–67.9	6	47.0–47.9	28	49.0–49.9	20
57.0–57.9	78	42.0–42.4	73	68.0–68.9	7	48.0–48.9	26	50.0–50.9	20
58.0–58.9	35	42.5–42.9	48	69.0–69.9	13	49.0–49.9	50	51.0–51.9	29
59.0–59.9	29	43.0–43.4	41	70.0–70.9	34	50.0–50.9	36	52.0–52.9	34
60.0–60.9	10	43.5–43.9	26	71.0–71.9	27	51.0–51.9	47	53.0–53.9	42
61.0–61.9	4	44.0–44.4	15	72.0–72.9	46	52.0–52.9	43	54.0–54.9	42
62.0–62.9	3	44.5–44.9	7	73.0–73.9	41	53.0–53.9	35	55.0–55.9	38
63.0–63.9	6	45.0–45.4	5	74.0–74.9	47	54.0–54.9	32	56.0–56.9	47
64.0–64.9	1	45.5–45.9	2	75.0–75.9	50	55.0–55.9	28	57.0–57.9	24
65.0–65.9	0	46.0–46.4	1	76.0–76.9	55	56.0–56.9	16	58.0–58.9	25
66.0–66.9	0			77.0–77.9	33	57.0–57.9	20	59.0–59.9	21
67.0–67.9	1			78.0–78.9	22	58.0–58.9	11	60.0–60.9	19
				79.0–79.9	27	59.0–59.9	5	61.0–61.9	18
				80.0–80.9	12	60.0–60.9	5	62.0–62.9	13
				81.0–81.9	5	61.0–61.9	3	63.0–63.9	1
				82.0–82.9	5	62.0–62.9	2	64.0–64.9	5
				83.0–83.9	2	63.0–63.9	5	65.0–65.9	3
				84.0–84.9	1	64.0–64.9	3	66.0–66.9	4
				85.0–85.9	1			67.0–67.9	2
								68.0–68.9	3
								69.0–69.9	2
Total....	450		450		450		450		450

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[1] For detailed references see Part I of this study, p. 30.

[2] Elderton, W. P. Frequency Curves and Correlation, London, 1907, pp. xiii +172

The units of grouping of the several measurements are as follows: Length, 1 mm.; breadth, 0.5 mm.; index, 1 per cent; bulk, 1 c. c.; weight, 1 gram. With slightly larger groupings the distributions would be somewhat smoother. For the analytical treatment (pp. 183–189) the grouping of the index, bulk, and weight has been doubled, but for present purposes, and for the determination of the correlation coefficients, the smaller grouping gives more accurate results. The chief constants of variation deduced from the above distributions are given in Table 2.

TABLE 2.—*Constants of variation in size and shape of Barred Plymouth Rock eggs.*

Character.	Mean.	Standard deviation.	Coefficient of variation.
Length .... millimeters..	56.322±0.076	2.386±0.054	4.237±0.096
Breadth .... do....	41.917± .041	1.378± .031	3.287± .074
Index .... per cent..	74.522± .120	3.788± .085	5.053± .115
Bulk .... cubic centimeters..	51.880± .135	4.233± .095	8.160± .181
Weight .... grams..	55.264± .147	4.622± .103	8.364± .189

From the above tables the following points may be noted:

1. The means for the various characters may be considered to give close approximations to the true values for normal eggs of Barred Plymouth Rock pullets. It is of interest in this connection to compare the values of Table 2 with those given by Willard and Shaw in Bulletin 159 of the Kansas Agricultural Experiment Station. This bulletin, while dealing chiefly with the chemical analysis of eggs, gives, among other things, the length and breadth measurements of a series of eggs from different breeds of poultry. The mean length and breadth of Plymouth Rock eggs as given on page 171 of the bulletin referred to are as follows:

Mean length = 56.15 mm.
Mean breadth = 41.53 mm.

These results are based upon the measurement of the eggs from only 6 different hens, and no statement of the age of these birds is given. It will be seen that considering the small numbers involved these results correspond very closely to the values given in Table 2.

2. Since the means of all the characters tabled do not differ greatly among themselves in absolute numerical value, it follows that the absolute variation, as measured by the standard deviation, is very nearly proportional to the relative variability as measured by the coefficient of variation. Consequently in comparing the several characters in respect to variability it makes little difference which measure one uses. On general grounds it is better to measure variability in proportion to the size of the thing varying. Consequently the discussion which follows will be chiefly based on the coefficients of variation.

3. The variation of the egg in length and breadth, both absolutely and relatively, is quite small. Variabilities of only 3 to 8 per cent

indicate that the distributions are closely grouped about their means. This is evident from inspection of the data of Table 1.

4. The egg is relatively more variable in length than in breadth. From the values given in Table 2 it appears that the difference between the coefficient of variation for the length and that for the breadth of the egg is 0.957 ± 0.121.[1] The difference is thus approximately eight times its probable error and certainly significant. This result, that the egg is more variable in respect to its length than in respect to its breadth, is only what might be expected in view of the factors concerned in the shaping of the egg. If a plastic body generally oval in shape gets its final definite form in the lumen of a tube it is obvious that there will be a greater opportunity for variation in its longitudinal dimensions than in any of its lateral dimensions. The degree of diversity which can occur in respect to lateral dimensions, or breadth of the egg, is primarily conditioned by the degree of tonus of the muscular layers of the wall of the oviduct. It is reasonable to suppose that in normal, healthy birds this will be a relatively constant factor.

As the absolute difference here is small, a better idea can be gained of the actual magnitude of the amount by which the egg is more variable in length than in breadth by a relative or percentage comparison. Taking coefficients of variation as the basis of comparison, it appears that length is more variable than breadth by an amount which is 29.1 per cent of the variability of the breadth and 22.6 per cent of the variability of the length. In other words, it may be said that the egg is roughly a fourth more variable in length than it is in breadth.

5. The index is considerably more variable than either the length or breadth. Since the index is a mathematical function of the length and breadth it is possible to determine its mean and standard deviation from a knowledge of the means and coefficients of variation of the length and breadth. It was shown by Pearson[2] that for indices of the form $z=\frac{x_1}{x_2}$ the mean of z is $\frac{m_1}{m_2}(1+v^2_2-r_{1,2}v_1v_2)$, and that the standard deviation of z is $\frac{m_1}{m_2}\sqrt{v^2_1+v^2_2-2r_{1,2},v_1v_2}$, where m_1 and m_2 are the means of x_1 and x_2; v_1 and v_2 are the coefficients of variation *divided by 100*, and $r_{1,2}$ denotes the coefficient of correlation between x_1 and x_2. Substituting the proper values from Table 2 in these formulæ and evaluating, we have

Calculated mean index = 74.548
Calculated standard deviation of index = 3.833

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[1] This probable error is calculated by the ordinary formula for the probable error of a difference.

[2] Pearson, K. On a Form of Spurious Correlation which may arise when Indices are used in the Measurement of Organs. Proc. Roy. Soc., vol. 60, pp. 489–498, 1897.

These values each differ by less than 0.05 from the values determined directly from the observations in Table 2. This difference is well within the probable error of each constant. Considering the grouping of the data, these formulæ give excellent values, and furnish an additional check on the accuracy of the arithmetic involved in the calculation of the constants of Table 2.

6. The bulk and weight are much more variable than any of the other characters discussed. The bulk appears to be slightly the less variable of the two, both absolutely and relatively, although the difference between the coefficients of variation there is only about 0.2, and is probably not significant. The bulk and weight of the egg are almost twice as variable as the length and more than two and one-half times as variable as the breadth.

It is of interest to note that the variability of these egg characters is of about the same degree as that exhibited by similar characters of the human skull. Table 3 shows a few coefficients of variation for skull characters.

TABLE 3.—*Variation in certain skull measurements in man.*

Character.	Coefficient of variation.
Skull:	
Length (English)[1]	3.31
Length of base[1]	4.07
Greatest breadth[1]	3.75
Least breadth of forehead[1]	4.29
Height[1]	4.21
Cross circumference[1]	3.70
Ratio of height to greatest length[1]	3.80
Ratio of height to horizontal length[1]	4.61
Height to breadth index[1]	4.86
Breadth to height index[1]	4.83
Capacity[1]	8.28
Brain weight (Bavarian)[2]	8.12

[1] Macdonell, W. R. Biometrika, Vol. III, p. 222.

[2] Pearl, R. Biometrika, Vol. IV, p. 30. The Bavarian weights are given here because they represent about the average of several series from different nationalities.

From this table it will be noted that measurements of length, breadth, height, and circumference of the skull are subject to a variation of the same order of magnitude as egg length and breadth, namely, about 3 and 4 per cent. The skull indices exhibit a slightly smaller variation than those of the egg, averaging about 4.5 per cent. This is about 0.5 lower than the coefficient of variation for the egg index. The more important point is that in both cases the indices are more variable than the measurements upon which they are based. The difference between the coefficients of variation for index and length of eggs is less than the difference between the coefficients of length and breadth. The actual differences with the probable errors are:

$$\text{C. V. of index} - \text{C. V. of length} = 0.846 \pm 0.149$$

$$\text{C. V. of length} - \text{C. V. of breadth} = 0.857 \pm 0.121$$

When we consider measurements of weight and capacity, we find a still more marked increase in the variability in both eggs and skulls. In the case of skull capacity and brain weight the coefficient ranges about 8 per cent. This is practically the same value as that found for egg bulk and weight.

This close agreement between the egg of the domestic fowl and the human skull in respect to variation in size and shape is somewhat remarkable. At first thought it might be considered to be entirely fortuitous, but further consideration of the matter suggests the possibility that this is not the case; but that, on the contrary, there is a real and definite analogy between the two things, when considered from the standpoint of developmental mechanics. When we measure the shape, size, and capacities of either egg or skull, we are dealing with bodies having at least the following points in common:

1. Hollow structure, with hard, firm wall. In its development this structure passes through stages in which the wall is to some degree plastic and capable of being molded into different forms.
2. Both are normally completely filled at the time when their definite shape is being fixed with a soft, semifluid substance which is increasing in volume either by growth or by absorption of fluid. In other words, in both cases there is exerted on the outer walls some degree of pressure from within while this wall is in a plastic stage.
3. In both cases muscular pressure is brought to bear on the wall from the outside during the period when it is in a plastic condition and while its definitive shape is being fixed. In the one case (the skull) this pressure is exerted by muscles (temporal and masseter muscles chiefly) which have their attachment upon the outside of the wall itself. In the other case (the egg) the external pressure comes from the intrinsic muscle layers of the walls of the uterus or "shell gland."

The size and shape of an egg are determined by a complex of what may be spoken of as intrinsic and extrinsic factors. On the one hand in influencing size we have as a primary intrinsic factor the size of the yolk (determined by the deposition of yolk before the ovum is discharged from the ovary). On the other hand as extrinsic factors may be distinguished (*a*) the amount of albumen secreted, (*b*) the tonic condition of the muscular walls of the oviduct in determining the manner in which the albumen shall be deposited about the yolk, (*c*) the muscular activity of the walls of the uterus in molding the shell as it is secreted about the albumen and its inclosing shell membrane. So far as concerns the actual determination of the size and shape of the shell, the secretion of albumen should be regarded as an intrinsic factor. Observations[1] made in this laboratory show that after the shell membrane has been secreted around the albumen by the glands in the isthmus, the egg increases in weight by a considerable amount. This means that pressure is being exerted upon the formed membrane from within. The observations referred to show further that the increase in weight is due to the passage of fluids into the egg by osmosis. So then, when the shell is being formed and is receiving its definite shape we may think of something like the following processes occurring: On the one hand, the shell membrane is being kept tense and in places where it is least resistant is being bulged out by the pressure from within. On the other hand, the muscular walls of the uterus are pressing upon this membrane and forming shell, from without, and molding it into the definite shape which becomes fixed as the shell hardens.

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[1] Pearl, R., and Curtis, M. R. Studies on the Physiology of Reproduction in the Domestic Fowl. V. Data Regarding the Physiology of the Oviduct. Jour. Exp. Zool., vol. 12, pp. 99–132, 1912.

If we may suppose that a set of processes essentially similar in their mechanical action and results to those which have been described as determining the shape of the egg are operative in the determination of the definitive form of the skull we then have a definite basis for the observed close similarity in variation of these two structures. That these two factors of internal pressure (from the growing brain) and the external molding action of the temporal muscles are of primary importance in the developmental mechanics of the skull is a view which has been definitely advocated by certain anthropologists. Thomson[1] had this to say in regard to the matter (*loc. cit.*, p. 682):

> For purposes of convenience, it may be well to group the influences at work in the determination of cranial form under two heads:
>
> (*a*) Those operative from within.
>
> (*b*) Those operative from without.
>
> The former includes such factors as volume of brain, growth of sutures, and ossification of bones, compensation as to balance of head, heredity and breeding. The latter embraces muscular influence dependent upon jaw development more or less intimately related to the size of the teeth and consequently associated with diet. In this way environment plays a part in the modification of man's cranial form in the same manner as it is productive of the variety of shapes met with in other types.

Thomson demonstrates by means of models how the primary factors of internal pressure and muscular action operate to influence the form of the skull.

To summarize this discussion, it may be said that in the first place it is a fact that in respect to the variability of their chief dimensions—length, breadth, length-breadth index, capacity, and weight of contents—the egg of the domestic fowl and the human skull show a very close similarity.[2]

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[1] Thomson, A. Cranial Form in Man, together with some Remarks on the Attitude of the Profession toward Anthropology. Medical Record, vol. 3, pp. 681-687, 1903.

[2] The human skull is taken for illustration in this discussion simply because it has been more thoroughly studied from a biometric standpoint than the skull of any other higher vertebrate. The work of Hatai (Amer. Jour. Anat., vol. VIII, p. 432) on the skull of the white rat indicates that the general features regarding variation and correlation in skull characters are probably similar in all of the mammals.

A consideration of the processes concerned in the production of the definitive size and shape of both of these structures suggests, though it does not prove, that this similarity with reference to variation constants is not fortuitous but rests upon a basis of general similarity in regard to mechanical factors operative in both cases during the development and fixation of the final form.

NATURE OF THE FREQUENCY DISTRIBUTIONS.

Having presented the general facts regarding variation in egg size and shape we may next turn to the analytical discussion of these frequency distributions. In the mathematical analysis the methods of Pearson have been used. A detailed analysis has been carried out and fitted curves obtained for the distributions of length, breadth, index, bulk, and weight of the 450 eggs of series A. Both for convenience in calculation and to secure somewhat smoother distributions, the data with regard to index, bulk, and weight were grouped in larger units than in Table 1. Table 4 gives the distributions as they were used for purposes of graduation.

TABLE 4.—*Frequency distributions used in the analytical discussion.*

[Data from Series A.]

Length.[1]		Breadth.[1]		Index.		Bulk.		Weight.	
Millimeters.	Frequency.	Millimeters.	Frequency.	Per cent.	Frequency.	Cubic centimeters.	Frequency.	Grams.	Frequency.
49.5	1	38.25	2	61.0	2	41.0	2	42.0	1
50.5	1	38.75	4	63.0	3	43.0	8	44.0	1
51.5	7	39.25	9	65.0	6	45.0	20	46.0	9
52.5	22	39.75	18	67.0	11	47.0	53	48.0	27
53.5	36	40.25	41	69.0	20	49.0	76	50.0	40
54.5	71	40.75	52	71.0	61	51.0	83	52.0	63
55.5	68	41.25	41	73.0	87	53.0	78	54.0	84
56.5	77	41.75	65	75.0	97	55.0	60	56.0	85
57.5	78	42.25	73	77.0	88	57.0	36	58.0	49
58.5	35	42.75	48	79.0	49	59.0	16	60.0	40
59.5	29	43.25	41	81.0	17	61.0	8	62.0	31
60.5	10	43.75	26	83.0	7	63.0	7	64.0	6
61.5	4	44.25	15	85.0	2	65.0	3	66.0	7
62.5	3	44.75	7					68.0	5
63.5	6	45.25	5					70.0	2
64.5	1	45.75	2						
65.5	0	46.25	1						
66.5	0								
67.5	1								

---

[1] The distributions for length and breadth are the same as in Table 1. They are repeated here for convenience.

The units of grouping for the various characters are as follows: Length, 1 mm.; breadth, 0.5 mm.; index, 2 per cent; bulk, 2 c. c.; weight, 2 grams. In Table 5 are set forth the analytical constants for the distributions of Table 4. The moments are given in terms of the units of grouping stated above. The values for the mean, mode, standard deviation, and y_0 are in terms of the units of measurements.

TABLE 5.—*Analytical constants of variation in egg size and shape.*

[Data from Series A.]

Constant.	Length.	Breadth.	Index.	Bulk.	Weight.
	Mm.	*Mm.*	*Per cent.*	*C. c.*	*Grams.*
Mean	56.3222	41.9167	[1] 74.5556	[1] 51.8400	[1] 55.2400
Standard deviation	2.3862	1.3777	[1] 3.7503	[1] 4.2438	[1] 4.5923
Coefficient of variation	4.2367	3.2868	[1] 5.0302	[1] 8.1964	[1] 8.3133
μ_2	+ 5.6940	+ 7.5922	+ 3.5162	+ 4.5025	+ 5.2723
μ_3	+ 8.3979	+ 2.7141	+ 2.6249	+ 3.6878	+ 4.2776
μ_4	+141.7823	+166.1906	+46.4494	+64.8049	+90.1964
β_1	0.3820	0.0168	0.1585	0.1490	0.1249
β_2	4.3732	2.8832	3.7561	3.1967	3.2448
$\sqrt{\beta_1}$	0.6181	0.1297	0.3981	0.3860	0.3533
β_2-3	+ 1.3732	− 0.116842	+ 0.7561	+ 0.1967	+0.2448
κ_1	+ 1.6002	− 0.2842	+ 1.0367	− 0.0536	+0.1151
κ_2	+ 0.1985	− 0.0446	+ 0.1199	− 2.1636	+0.8388
Skewness	+ 0.2155	....	− 0.1523	+ 0.1964	+0.1704
Modal divergence	+ 0.5142	....	− 0.5712	+ 0.8335	+0.7825
Mode	55.8080	....	75.1268	51.0065	54.4575
Type of curve	IV	II	IV	I	V
+ end of curve	$+\infty$	51.5951	$+\infty$	260.6816	....
− end of curve	$-\infty$	32.2383	$-\infty$	32.0609	2.8514
y_0	26.345	64.157	41.887	90.472	[2] ......

[1] These values for the mean, standard deviation, and coefficient of variation for the index, bulk, and weight were calculated from the distributions in Table 4. Since the units of grouping in this case are twice as large as for the same characters in Table 1, the values differ slightly from those previously given. The differences, however, are insignificant in comparison with their probable errors as given in Table 2.

[2] In Type V curves y_0 very often has a very large value. In this case the logarithm of $y_0 = 247.66959$.

The first thing that is noted from this table is that there is no uniformity in regard to the type of curve demanded by the several characters under discussion. The criterion ($\kappa_1 = 2\beta_2 - 3\beta_1 - 6$) is negative in only two cases, viz, the breadth and bulk. This is the condition for either a Type I or a Type II curve. In regard to the breadth β_1 does not differ significantly from zero, and hence the curve is symmetrical. It is accordingly fitted with a Type II curve. In the bulk distribution, however, β_1 is significantly greater than zero and hence demands a curve of Type I.

In the other distributions κ_1 is positive. This suggests that the distributions belong to Pearson's Type IV curve, but in order to determine this it is necessary to know in addition the value of

$$\kappa_2 = \frac{\beta_1(\beta_2+3)^2}{4(4\beta_2-3\beta_1)(2\beta_2-3\beta_1-6)}$$

To fulfill the condition of a Type IV curve the value of κ_2 must be >0 and <1. Strictly speaking this is true for all three of the remaining distributions and accordingly they could be fitted with Type IV. This has been done in the case of the length and index. In regard to the weight, however, the value of κ_2 ($=+0.84$) so nearly approaches unity that having regard to the probable errors of the β's it may be looked upon as not significantly <1. We shall thus very likely get a better fit by using the transition curve of Type V.

The equations of the theoretical curves are as follows:

Length:

$$y = \frac{26.2446}{\left\{1+\left(\frac{x}{6.8278}\right)\right\}^{6.6076}} \cdot e^{5.5811 \tan^{-1} x/6.8278}$$

Breadth:

$$y = 64.157\left\{1 - \frac{x^2}{374.6880}\right\}^{23.1757}$$

Index:

$$y = \frac{41.887}{\left\{1 + \left(\frac{x}{6.5901}\right)^2\right\}^{8.5172}} \cdot e^{5.5494 \tan^{-1} x/6.5901}$$

Bulk:

$$y = 90.472\left(1 + \frac{x}{9.4728}\right)^{19.8392}\left(1 - \frac{x}{104.8375}\right)^{208.4977}$$

Weight:[1]

$$\text{Log } y = 247.6695959 + 133.1410 \log\left(\frac{1}{x}\right) + \overline{1492}.1386\frac{1}{x}$$

The histograms and their fitted curves are given in figures 1–5. It is evident that the graduations are as good as could be expected for the distributions.

From Tables 4 and 5 and figures 1–5 we note the following points:

1. The skewness is positive for all characters except the index. In each case the value of the constant is numerically small, but with the exception of the breadth it is significant. The probable error of the skewness on the assumption that the distribution follows the normal curve of errors is given by the formula

$$P.\ E._{sk} = 0.67449\sqrt{\frac{3}{2N}}$$

In these distributions N is 450 and we have

$$P.\ E._{sk} = \pm 0.0389,$$

for all distributions.

The skewness of the breadth distribution is less than twice the probable error and consequently the distribution does not deviate sensibly from the normal curve. Of the remaining distributions the skewness for the index is the smallest. This, however, is more than five times the probable error, and the distribution is certainly significantly asymmetrical. The length distribution shows the greatest skewness and the breadth the smallest.

2. The distance from the mean to the mode ($d = Sk.\sigma$) is again significant in all distributions except that for the breadth. For the normal distribution the probable error of $d = P.\ E._{sk} \times \sigma$. For this breadth distribution it is equal to ±0.150. The values of d for the bulk and weight distributions approach each other rather closely and are the largest of the five values.

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[1] For obvious reasons this curve is put in the logarithmic form. The equation to a curve of Type V is $y = y_0 x^{-p} e^{-\gamma/x}$.

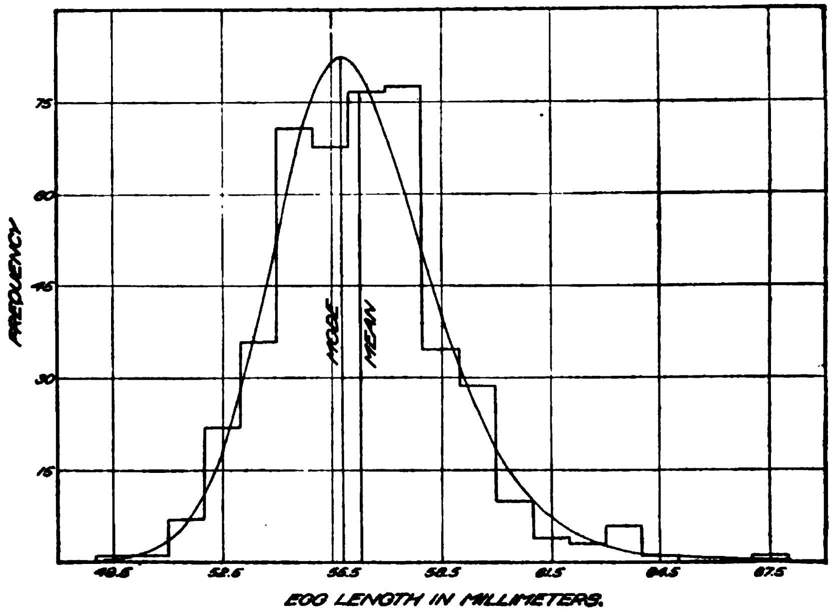

FIG. 1.—Histogram and fitted curve for variation of eggs in length.

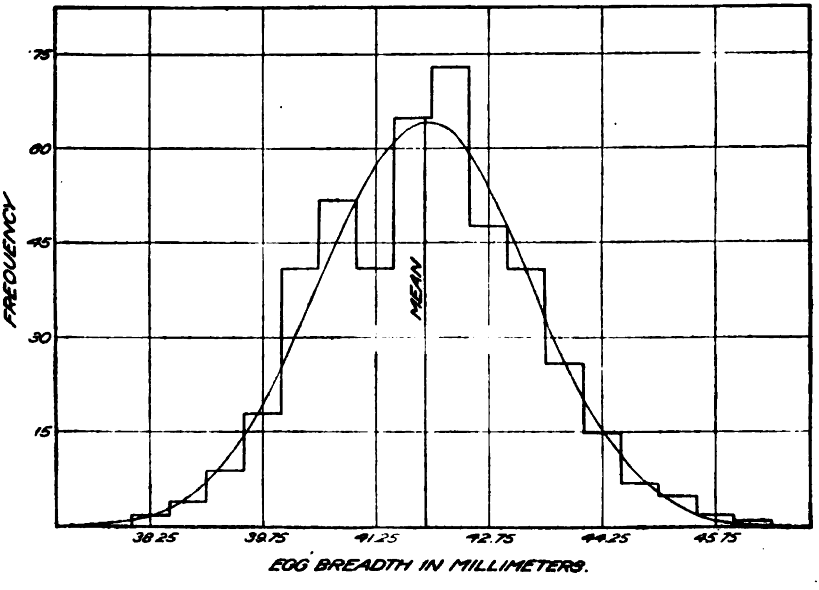

FIG. 2.—Histogram and fitted curve for variation of eggs in breadth.

3. The kurtosis ($\eta = \beta_2 - 3$) is positive or greater than zero in all the distributions except that for the breadth. Since the

$$P.\ E._{\beta_2} = 4\ P.\ E._{sk} = \pm 0.1556$$

the kurtosis of the breadth, bulk, and weight does not differ significantly from zero. These curves are thus mesokurtic. From the graphs (figs. 1–5) it is evident that the curves for bulk and weight are rather more peaked than the mesokurtic condition. On the other hand the kurtosis of the curves for length and index is significantly positive, thus indicating a leptokurtic or peaked curve. This is shown in figures 1 and 3.

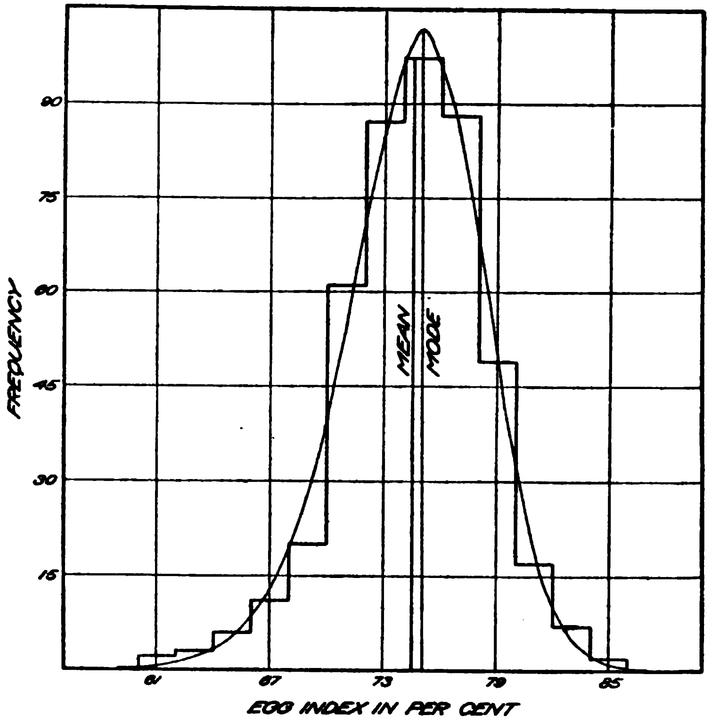

FIG. 3.—Histogram and fitted curve for variation of eggs in shape, as measured by length-breadth index.

4. In only three cases are the theoretical curves of limited range. In the curve for variation in breadth the estimation of both ends of the range is very good. This is seen if the values given for the range ends are compared with the observed measurements of extremely large and small eggs. In the direction of large size the cases of triple-yolked eggs are to be considered. The measurements given by Akers[1] for such a specimen lead to a breadth of about 52 mm. Small eggs with a diameter of 30–35 mm. are not uncommonly found. In

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[1] Akers, L. C. A Three-yolked Egg. Farm Poultry, vol. 16, p. 558, 1905.

the case of the curve for variation in bulk the lower range end is a very fair estimation. The upper range, however, is considerably overestimated. A volume of 260 c. c. would certainly mean an exceptionally large egg, and perhaps a physically impossible value. A triple-yolked egg studied in this laboratory had a volume of 79.1 c. c.[1] From the weight of Akers' specimen (4½ oz. = 127.6 gms.) we would estimate the bulk to be about 120 c. c., on the basis of correlation data discussed farther on in this bulletin. Since this value seems to approach the limit of observed eggs, it is hardly likely that an egg with a volume of over 200 c. c. would be found among hen's eggs. In this connection it must be noted that the frequency above say 70 c. c. is very small and practically negligible. Thus the expected absolute frequency of eggs with a bulk of 80 c. c. is, according to the theoretical curve, 0.000118, or the expectation is that one would get 3 such eggs out of every 10,000,000 examined. The expectation of getting eggs with a bulk of 100 c. c. is about 5 in every 100,000,000,000,000. These two values taken as examples roughly correspond to the average bulks for double and triple-yolked eggs respectively. It is evident that the theoretical curve underestimates the frequency of such eggs.

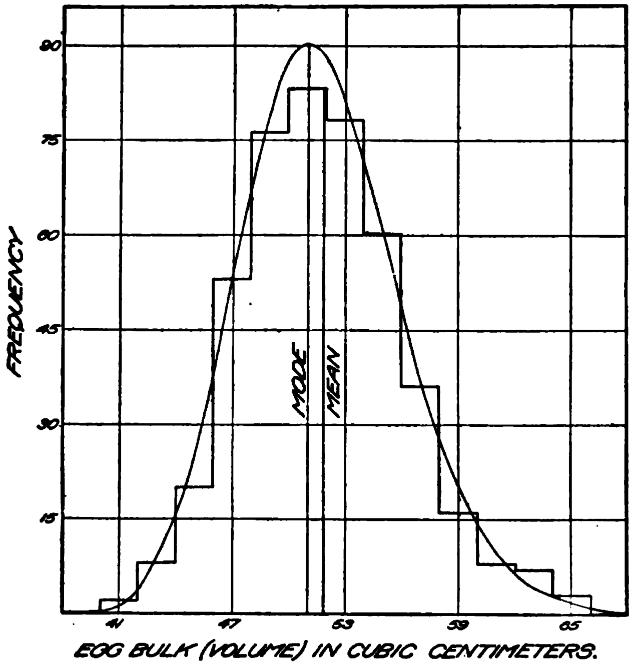

FIG. 4.—Histogram and fitted curve for variation of eggs in bulk.

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[1] Pearl, R. A Triple-yolked Egg. Zool. Anz. Bd. XXXV, pp. 417-432, 1910.

Valenciennes[1] stated that marketmen in Paris find about 3 double-yolked eggs in every 14,000,000 eggs handled. Market data on such a question, however, can not be a very reliable indication of the actual frequency with which double-yolked eggs occur, for most double-yolked eggs are never sent to market. It is more likely that the actual frequency of double-yolked eggs is nearer 1 to every 5,000 or 6,000 eggs laid. In any event it is evident from the preceding discussion that variation in the bulk of double-yolked eggs must follow some other law than that which describes the variation of normal eggs in respect to the characters.

The theoretical curve for variation in weight is of Type V, which is a curve limited in one direction only. In this case we have the lower range limit at 2.85 grams. This clearly underestimates the weight of the smallest of normal eggs, our lowest observed value being 42 grams. However, here again the expected frequency below 40 is practically negligible. The expectation at 40 grams is less than 0.5 of an egg per 1,000. The upper range is unlimited, but it is evident from the graph of the theoretical curve (fig. 5) that it makes considerable allowance for eggs heavier than any observed. Thus the curve passes 70 grams, the highest observed value, with a frequency of about 2.6 eggs per 1,000.

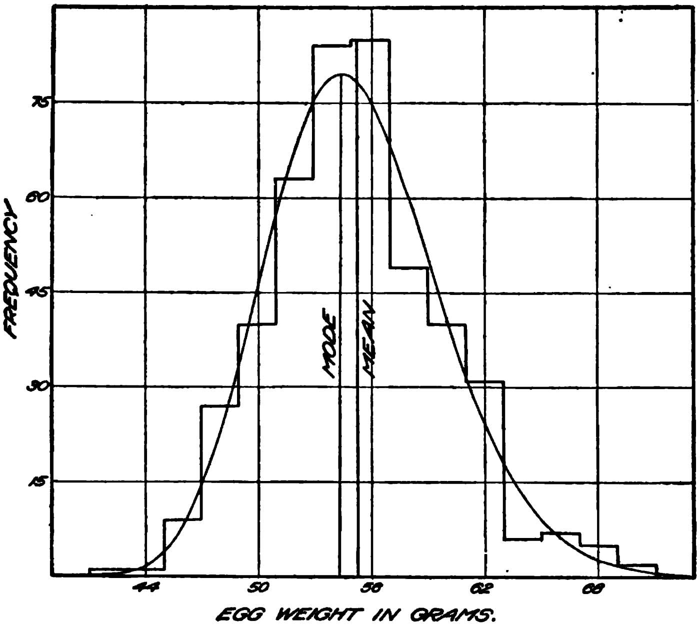

FIG. 5.—Histogram and fitted curve for variation of eggs in weight.

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[1] Valenciennes. Note sur les œufs à plusieurs jaunes contenus dans la même coque. C. R., Ac. Sci. Paris, T. 42, pp. 3–6, 1856.

THE CORRELATION OF THE BARRED PLYMOUTH ROCK EGG IN RESPECT TO SIZE AND SHAPE CHARACTERS.

Having considered the variation of eggs in the size and shape characters taken singly, we may next turn to the problem of correlation in the variation of these characters. The size of an egg is primarily determined by a set of physiological processes entirely different from those which fix its shape. On this account it is of considerable theoretical interest to know the degree of correlation which exists between the shape and the size of eggs. Do eggs of a certain shape always have a larger volume than eggs of another shape?

It is also of importance, both theoretically and practically, to know the relation between the bulk and weight and the two diameters of eggs. Is an exceptionally long egg likely to have an exceptionally large volume? Will one be more likely to get an exceptionally large, heavy egg if he selects long eggs than if he selects broad eggs?

From the standpoint of causal morphology (Entwicklungsmechanik) the comparison between the correlations found in the size and shape characters of eggs and those and similar characters in the vertebrate skull is of much interest. These considerations apply with reference to the length and breadth dimensions of the egg. If, as has been previously proposed,[1] the chief factor in determining the shape of an egg is the contraction of the uterine muscles, we could scarcely expect a high degree of correlation between length and breadth. If such should be found it would indicate a greater degree of coordination of muscular contractions in such an organ than has hitherto been supposed to exist.

The data used in this section are those contained in Series A. This consists of the measurements of 450 eggs. As in the previous section, five characters are dealt with here. These are length, breadth, index, bulk, and weight. Arranging these in all possible pairs, we get 10 combinations. It is thus necessary to obtain 10 coefficients of correlations. Two of these correlations (namely, index with length and with breadth) will be obtained by means of formulæ. For the other eight correlations, it is necessary to form the usual correlation tables. These are shown below in Tables 6 to 14, inclusive. The units of grouping used in these tables are the same as those employed in calculating the variation constants (p. 178).

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[1] Pearl, R. Jour. Exp. Zool., vol. 6, pp. 339–359, 1909.

TABLE 6.—*Showing the correlation of egg length and egg breadth.*

	Egg breadth, in millimeters.																	Total.
Egg length, in millimeters.	38.0–38.4	38.5–38.9	39.0–39.4	39.5–39.9	40.0–40.4	40.5–40.9	41.0–41.4	41.5–41.9	42.0–42.4	42.5–42.9	43.0–43.4	43.5–43.9	44.0–44.4	44.5–44.9	45.0–45.4	45.5–45.9	46.0–46.4	
49.0–49.9					1													1
50.0–50.9						1												1
51.0–51.9		1			1	1			1	1	2							7
52.0–52.9				1	2	5	3	2	4	1	3	1						22
53.0–53.9		1	2	1	3	4	6	2	8	4	2	2	1					36
54.0–54.9	1		1	3	9	11	4	15	12	3	8	4						71
55.0–55.9			1	3	6	3	7	11	13	9	3	4	4	2	2			68
56.0–56.9	1		1	5	9	8	6	9	8	9	11	4	3	2	1			77
57.0–57.9			1	2	6	8	6	17	14	11	2	6	4				1	78
58.0–58.9			2	1		3	6	2	4	3	7	3	1		1	2		35
59.0–59.9					3	2	3	2	8	4	3	1	1	1	1			29
60.0–60.9		1		1	1	1		3	1					2				10
61.0–61.9						3						1						4
62.0–62.9		1				1		1										3
63.0–63.9				1		1				3			1					6
64.0–64.9			1															1
65.0–65.9																		0
66.0–66.9																		0
67.0–67.9								1										1
Total.....	2	4	9	18	41	52	41	65	73	48	41	26	15	7	5	2	1	450

TABLE 7.—*Showing the correlation between egg length and egg weight.*

	Egg weight, in grams.																												Total.
Egg length, in millimeters.	42.0–42.9	43.0–43.9	4 .0–44.9	45.0–45.9	46.0–46.9	47.0–47.9	48.0–48.9	49.0–49.9	50.0–50.9	51.0–51.9	52.0–52.9	53.0–53.9	54.0–54.9	55.0–55.9	56.0–56.9	57.0–57.9	58.0–58.9	59.0–59.9	60.0–60.9	61.0–61.9	62.0–62.9	63.0–63.9	64.0–64.9	65.0–65.9	66.0–66.9	67.0–67.9	68.0–68.9	69.0–69.9	
49.0–49.9		1																											1
50.0–50.9						1																							1
51.0–51.9	1					1	1				1	2	1																7
52.0–52.9				1	1	3	3	2	1	5		3	1	1	1														22
53.0–53.9				1	2	2	3	3	2	6	6	2	4	2	1	1				1									36
54.0–54.9				1	2	1	6	8	4	5	11	9	8	3	7	2	4												71
55.0–55.9					1	1	3	1	4	4	3	5	15	6	8	5	4	1	1	3	3								68
56.0–56.9						1		4	5	6	6	8	4	7	8	5	7	5	5	3	2			1					77
57.0–57.9							1	1	2	2	4	8	5	11	15	5	4	8	2	5	3	1					1		78
58.0–58.9								1	1	1		2	3	4	1	1	1	3	7	4	2			1	2		1		35
59.0–59.9											1	3		2	3	3	3	2	2	2	3		2	1		1		1	29
60.0–60.9									1		1				1	1	2	1	1						1		1		10
61.0–61.9														1	2											1			4
62.0–62.9											1							1	1										3
63.0–63.9													1			1							3					1	6
64.0–64.9														1															1
65.0–65.9																													0
66.0–66.9																													0
67.0–67.9																									1				1
Total....	1	1	0	3	6	10	17	20	20	29	34	42	42	38	47	24	25	21	19	18	13	1	5	3	4	2	3	2	450

TABLE 8.—*Showing the correlation between egg length and egg bulk.*

Egg bulk, in cubic centimeters.	Egg length, in millimeters.																			
	49.0–49.9	50.0–50.9	51.0–51.9	52.0–52.9	53.0–53.9	54.0–54.9	55.0–55.9	56.0–56.9	57.0–57.9	58.0–58.9	59.0–59.9	60.0–60.9	61.0–61.9	62.0–62.9	63.0–63.9	64.0–64.9	65.0–65.9	66.0–66.9	67.0–67.9	Total.
40.0–40.9			1																	1
41.0–41.9						1														1
42.0–42.9	1				1															2
43.0–43.9			1	1	2	1		1												6
44.0–44.9		1		3	1															5
45.0–45.9			1	4	2	5	2	1												15
46.0–46.9				2	5	9	4	3	1	1										25
47.0–47.9				1	3	9	6	5	2	1		1								28
48.0–48.9			1	4	3	3	1	8	4	1				1						26
49.0–49.9			1	3	8	12	7	7	9	1	1	1								50
50.0–50.9			2		5	10	8	5	3	1	2									36
51.0–51.9				2	1	6	12	10	6	5	2	1			1	1				47
52.0–52.9				2	2	5	7	5	13	3	3	1	2							43
53.0–53.9					2	7	5	5	14	1			1							35
54.0–54.9						3	5	7	8	3	2	2		1	1					32
55.0–55.9					1		3	9	5	3	6	1								28
56.0–56.9							2	3	2	2	5	1		1						16
57.0–57.9							3	5	5	6	1									20
58.0–58.9							1	1	3	3	3									11
59.0–59.9							1	1	2		1									5
60.0–60.9							1	1		1					2					5
61.0–61.9											1		1		1					3
62.0–62.9										1									1	2
63.0–63.9										2	2	1								5
64.0–64.9									1			1			1					3
Total....	1	1	7	22	36	71	68	77	78	35	29	10	4	3	6	1	0	0	1	450

TABLE 9.—*Showing the correlation between egg breadth and egg weight.*

Egg breadth, in millimeters.	Egg weight, in grams.																												
	42.0–42.9	43.0–43.9	44.0–44.9	45.0–45.9	46.0–46.9	47.0–47.9	48.0–48.9	49.0–49.9	50.0–50.9	51.0–51.9	52.0–52.9	53.0–53.9	54.0–54.9	55.0–55.9	56.0–56.9	57.0–57.9	58.0–58.9	59.0–59.9	60.0–60.9	61.0–61.9	62.0–62.9	63.0–63.9	64.0–64.9	65.0–65.9	66.0–66.9	67.0–67.9	68.0–68.9	69.0–69.9	Total.
38.0–38.4				1		1																							2
38.5–38.9	1			1					1		1																		4
39.0–39.4					3	1		2	1	1				1															9
39.5–39.9				1	2	1	4	4	3	1	1		1																18
40.0–40.4		1			1	2	7	6	8	6	4	5			1														41
40.5–40.9						5	5	6	4	7	7	6	4	3	2	2		1											52
41.0–41.4							1	2	3	7	4	11	5	5	2	1													41
41.5–41.9										3	7	10	12	16	9	3	1	1	2						1				65
42.0–42.4										4	8	5	15	8	15	4	7	5	2										73
42.5–42.9											2	3	3	1	9	8	5	8	2	3	1		3						48
43.0–43.4												2	2	4	6	3	7	3	7	3	3		1						41
43.5–43.9															3	2	4	2	3	6	3	1	1			1			26
44.0–44.4																1	1	1	3	3	3			2				1	15
44.5–44.9																				3	1				1	1	1		7
45.0–45.4																					2			1	1			1	5
45.5–45.9																									1		1		2
46.0–46.4																											1		1
Total....	1	1	0	3	6	10	17	20	20	29	34	42	42	38	47	24	25	21	19	18	13	1	5	3	4	2	3	2	450

TABLE 10.—*Showing the correlation between egg breadth and egg bulk.*

	Egg bulk, in cubic centimeters.																									
Egg breadth, in millimeters.	40.0–40.9	41.0–41.9	42.0–42.9	43.0–43.9	44.0–44.9	45.0–45.9	46.0–46.9	47.0–47.9	48.0–48.9	49.0–49.9	50.0–50.9	51.0–51.9	52.0–52.9	53.0–53.9	54.0–54.9	55.0–55.9	56.0–56.9	57.0–57.9	58.0–58.9	59.0–59.9	60.0–60.9	61.0–61.9	62.0–62.9	63.0–63.9	64.0–64.9	Total.
38.0–38.4		1		1																						2
38.5–38.9	1		1					1	1																	4
39.0–39.4				3		2	2	1				1														9
39.5–39.9				1	1	4	4	4	1	2		1														18
40.0–40.4			1	1	2	4	11	6	10	3	2	1														41
40.5–40.9					2	5	6	12	2	13	3	3	3	1	2											52
41.0–41.4							2	4	7	8	7	8	4	1												41
41.5–41.9									2	14	11	12	17	2	4	1	1						1			65
42.0–42.4									3	8	8	17	7	14	6	7	3									73
42.5–42.9										2	3	2	6	7	13	7	4	1			2	1				48
43.0–43.4											2	2	5	7	3	8	5	6	3							41
43.5–43.9													1	3	4	4	1	6	5	1		1				26
44.0–44.4																1	2	6	1	2	1	1			1	15
44.5–44.9																		1	2	1				2	1	7
45.0–45.4																				1	2		1	1		5
45.5–45.9																								2		2
46.0–46.4																									1	1
Total.....	1	1	2	6	5	15	25	28	26	50	36	47	43	35	32	28	16	20	11	5	5	3	2	5	3	450

TABLE 11.—*Showing the correlation between egg index and egg weight.*

	Egg weight, in grams.																												
Egg index, in per cent.	42.0–42.9	43.0–43.9	44.0–44.9	45.0–45.9	46.0–46.9	47.0–47.9	48.0–48.9	49.0–49.9	50.0–50.9	51.0–51.9	52.0–52.9	53.0–53.9	54.0–54.9	55.0–55.9	56.0–56.9	57.0–57.9	58.0–58.9	59.0–59.9	60.0–60.9	61.0–61.9	62.0–62.9	63.0–63.9	64.0–64.9	65.0–65.9	66.0–66.9	67.0–67.9	68.0–68.9	69.0–69.9	Total.
60.0–60.9														1															1
61.0–61.9																									1				1
62.0–62.9											1		1																2
63.0–63.9						1																							1
64.0–64.9									1					1		1													3
65.0–65.9											1							1					1						3
66.0–66.9															3				1				1						5
67.0–67.9								1	1		1	2											1						6
68.0–68.9						1		1		1		1		1	1	1													7
69.0–69.9							2		2	1	1	1		2	1		1	1	1										13
70.0–70.9				1	1			4	2	4	2	4	5	2		3	3	1	1									1	34
71.0–71.9		1			1		1		3	2	1	4	1	3	3	1	1	2		1	1					1			27
72.0–72.9				1	2	2	2	1	3	1	6	5	3	6	5	3	1	1	2	1	1								46
73.0–73.9					1		1	5		4	1	4	2	4	6			2	3	2	2		2		1		1		41
74.0–74.9							4	1	4	3	2	3	3	5	7	2	3	4	3	2				1					47
75.0–75.9	1			1		1	1	4	1	1	3	4	5	5	6	3	4	3	2	2	1			1		1			50
76.0–76.9					1	1	1	2	2	2	6	3	11	2	3	4	5	3	1	3	3	1						1	55
77.0–77.9						2	1		1	3	1	3	4	1	4	3		2	4	1	1				2				33
78.0–78.9							3	1		3	2	1	2	2	2		1		1	2	1						1		22
79.0–79.9						2	1			2	4	2	3	1	3	1	5	1		1				1					27
80.0–80.9										2	1	1		1	1	1	1			2	1						1		12
81.0–81.9												1			1					1	2								5
82.0–82.9											1	1	1	1		1													5
83.0–83.9												1			1														2
84.0–84.9													1																1
85.0–85.9												1																	1
Total.....	1	1	0	3	6	10	17	20	20	29	34	42	42	38	47	24	25	21	19	18	13	1	5	3	4	2	3	2	450

TABLE 12.—*Showing the correlation of egg index and egg bulk.*

Egg index, in per cent.	Egg bulk, in cubic centimeters.																									Total.
	40.0–40.9	41.0–41.9	42.0–42.9	43.0–43.9	44.0–44.9	45.0–45.9	46.0–46.9	47.0–47.9	48.0–48.9	49.0–49.9	50.0–50.9	51.0–51.9	52.0–52.9	53.0–53.9	54.0–54.9	55.0–55.9	56.0–56.9	57.0–57.9	58.0–58.9	59.0–59.9	60.0–60.9	61.0–61.9	62.0–62.9	63.0–63.9	64.0–64.9	
60.0–60.9	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	1
61.0–61.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	1
62.0–62.9	...	...	...	...	...	...	...	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	2
63.0–63.9	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
64.0–64.9	...	...	...	...	...	...	...	1	...	...	...	...	1	...	1	...	...	...	...	...	...	...	...	...	...	3
65.0–65.9	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1	...	...	...	...	...	1	...	...	...	...	3
66.0–66.9	...	...	...	...	...	...	...	...	...	...	...	1	1	1	...	...	1	...	...	...	1	...	...	...	...	5
67.0–67.9	...	...	...	...	...	...	1	1	...	1	2	...	...	...	...	...	...	...	...	...	...	1	...	...	...	6
68.0–68.9	...	...	...	1	...	...	1	...	1	...	...	2	2	...	...	...	...	...	...	...	...	...	...	...	...	7
69.0–69.9	...	...	...	...	...	2	...	2	2	1	...	1	2	...	2	1	...	...	...	...	...	...	...	...	...	13
70.0–70.9	...	1	...	...	...	1	3	4	3	6	2	4	1	...	2	4	2	...	...	...	...	...	...	...	1	34
71.0–71.9	...	...	1	1	...	...	1	1	5	2	2	2	4	1	1	2	2	1	...	...	...	1	...	...	...	27
72.0–72.9	...	...	1	1	...	3	3	3	2	9	2	3	8	5	2	1	2	...	1	...	...	...	...	...	...	46
73.0–73.9	...	...	...	...	1	1	6	3	...	...	3	3	5	5	2	2	2	3	2	1	...	...	...	1	1	41
74.0–74.9	...	...	...	...	...	1	3	6	1	5	3	8	2	4	6	2	...	3	2	...	...	1	...	...	...	47
75.0–75.9	1	...	...	1	1	...	2	4	3	4	2	7	4	5	5	3	2	3	1	...	1	...	...	1	...	50
76.0–76.9	...	...	...	...	1	1	3	1	2	7	9	5	4	1	5	7	2	1	3	2	...	...	...	1	...	55
77.0–77.9	...	...	...	...	1	2	1	2	1	3	2	4	1	4	1	3	1	5	...	...	...	...	1	1	...	33
78.0–78.9	...	...	...	1	...	3	...	...	2	2	3	2	1	3	...	1	...	2	...	1	...	...	...	1	...	22
79.0–79.9	...	...	...	...	1	1	1	...	1	5	3	1	4	2	3	1	2	...	1	...	1	...	...	...	...	27
80.0–80.9	...	...	...	...	...	...	...	...	1	2	1	...	1	2	1	...	...	2	1	...	...	...	...	...	1	12
81.0–81.9	...	...	...	...	...	...	...	...	...	1	...	...	...	2	...	...	...	...	...	1	1	...	...	...	...	5
82.0–82.9	...	...	...	...	...	...	...	...	1	...	...	2	1	...	...	1	...	...	...	...	...	...	...	...	...	5
83.0–83.9	...	...	...	...	...	...	...	...	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	2
84.0–84.9	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
85.0–85.9	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
Total.....	1	1	2	6	5	15	25	28	26	50	36	47	43	35	32	28	16	20	11	5	5	3	2	5	3	450

TABLE 13.—*Showing the correlation between egg weight and egg bulk.*

Egg bulk, in cubic centimeters.	Egg weight, in grams.																												Total.
	42.0–42.9	43.0–43.9	44.0–44.9	45.0–45.9	46.0–46.9	47.0–47.9	48.0–48.9	49.0–49.9	50.0–50.9	51.0–51.9	52.0–52.9	53.0–53.9	54.0–54.9	55.0–55.9	56.0–56.9	57.0–57.9	58.0–58.9	59.0–59.9	60.0–60.9	61.0–61.9	62.0–62.9	63.0–63.9	64.0–64.9	65.0–65.9	66.0–66.9	67.0–67.9	68.0–68.9	69.0–69.9	
40.0–40.9	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
41.0–41.9	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
42.0–42.9	...	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2
43.0–43.9	...	...	...	1	2	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6
44.0–44.9	...	...	...	...	2	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5
45.0–45.9	...	...	...	...	2	3	8	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	15
46.0–46.9	...	...	...	...	...	2	3	11	8	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	25
47.0–47.9	...	...	...	...	...	...	5	8	6	8	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	28
48.0–48.9	...	...	...	...	...	...	...	...	5	12	6	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	26
49.0–49.9	...	...	...	...	...	...	...	...	1	7	19	16	6	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	50
50.0–50.9	...	...	...	...	...	...	...	...	...	...	6	16	13	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	36
51.0–51.9	...	...	...	...	...	...	...	...	...	...	2	6	17	17	5	...	...	...	...	...	...	...	...	...	...	...	...	...	47
52.0–52.9	...	...	...	...	...	...	...	...	...	...	...	1	6	17	18	1	...	...	...	...	...	...	...	...	...	...	...	...	43
53.0–53.9	...	...	...	...	...	...	...	...	...	...	...	...	...	2	19	10	3	...	...	1	...	...	...	...	...	...	...	...	35
54.0–54.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4	9	10	8	1	...	...	...	...	...	...	...	...	...	32
55.0–55.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	4	9	8	3	3	...	...	...	...	...	...	...	...	28
56.0–56.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	4	6	3	...	...	...	...	...	...	...	...	16
57.0–57.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	9	6	4	...	...	...	...	...	...	...	20
58.0–58.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5	4	1	1	...	...	...	...	...	11
59.0–59.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4	...	1	...	...	...	...	...	5
60.0–60.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	2	2	...	...	...	...	5
61.0–61.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	1	...	...	3
62.0–62.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	...	...	2
63.0–63.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	1	1	1	5
64.0–64.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	1	3
Total....	1	1	0	3	6	10	17	20	20	29	34	42	42	38	47	24	25	21	19	18	13	1	5	3	4	2	3	2	450

In Table 14 are exhibited the coefficients of correlation deduced from Tables 6 to 13, together with their probable errors. The correlation coefficients were determined according to the usual Bravais formula,

$$r=\frac{S(xy)}{N\sigma_1\sigma_2}$$

when x and y are the deviation from the means, and σ_1 and σ_2 are the standard deviations of the two variables.

Table 14.—*Coefficients of correlation. Egg size and shape. Series A.*

Characters.	Coefficient of correlation.	Characters.	Coefficient of correlation.
Length and breadth	+0.0837±.0316	**Length and weight**	+0.5797±.0211
Index and weight	+0.0851±.0316	**Breadth and weight**	+0.8357±.0096
Index and bulk	+0.1005±.0315	**Breadth and bulk**	+0.8602±.0083
Length and bulk	+0.5751±.0212	**Weight and bulk**	+0.9804±.0012

From Table 14 and the accompanying Tables 6–13, inclusive, the following points may be noted:

1. In every case the correlation is positive.

2. In Table 14 the coefficients of correlation are arranged in the order of their magnitude, beginning with the lowest and ending with the highest coefficient. Under this arrangement it is seen that the first three coefficients show very low values and are barely, if at all, significant. The next two show moderately high values, while the last three are exceptionally high.

3. In the case of the correlation between length and breadth, the coefficient is considerably less than three times its probable error. It is thus clear that there is very little if any correlation between variation in the length and the breadth of an egg. It seems most probable that the shape of an egg is determined by the molding influence of the longitudinal and circular muscles of the uterine wall. If the circular muscles contract more strongly than the longitudinal we shall get a relatively long and narrow egg. On the other hand a reduced tonus of the circular muscle layer, with relatively strong contractions of the longitudinal layer, will mean the production of a short, round egg. The absence of correlation between length and breadth of the egg indicates that these two sets of muscles are to a large degree independent in their action.

4. The next two coefficients, index and weight and index and bulk, may be considered together. These two coefficients do not differ greatly from each other. The difference is certainly not significant in comparison with its probable error (difference = 0.0154 ± 0.0446). The probable error is several times the difference. Further, neither

of these coefficients taken by itself can be considered as certainly significant. The coefficient for index and bulk is a little more than three times its probable error, while that for index and weight is slightly less than three times its probable error. However, from the fact that these two correlations in which index enters are both positive and of about the same value and these values approximately three times their probable errors, it can not safely be positively concluded that there is no correlation between the shape of an egg and its weight. The results, in fact, are not entirely conclusive. They appear to indicate that there is a slight correlation between the shape of an egg as measured by the length-breadth index and its bulk or weight. Thus a broad, short egg is on the average slightly more likely to have a larger proportionate capacity than a narrow, long egg.

5. Taking the next two correlations together (viz, length with bulk and length with weight), there is no question as to the significance of the coefficients. It is to be noted that these two coefficients, in which the length is correlated with the two measures of capacity, have approximately the same value. The difference between them is entirely insignificant.

6. The next two correlations are breadth with weight and breadth with bulk. These coefficients have exceptionally high values. Again it will be noted that the correlation of breadth with the two measures of capacity has about the same value in each case. The difference here, while greater than that mentioned in paragraph 5, is still not to be regarded as certainly significant. It is 0.0245 ± 0.0127. The results clearly show that inter-racially both egg length and egg breadth are highly correlated with the volume and weight. Of the two linear dimensions the breadth is distinctly more highly correlated with bulk characters than the length. That this difference is significant may be shown by taking the difference between the highest coefficient in which the length enters and the lowest one in which the breadth is concerned. This difference with its probable error is $0.8357 - 0.5797 = 0.2560 \pm 0.0232$. The difference is more than 10 times its probable error. As to the measure of capacity, it plainly makes little difference whether one uses the calculated volume in cubic centimeters or the actual weight in grams.

7. Turning finally to the correlation between weight and bulk, the very high coefficient of $+0.9804$ is noted. The significance of this is that the formula which has been used throughout for calculating the bulk gives excellent results. This is rather remarkable when it is remembered that in calculating the bulk the egg is regarded as a perfect prolate spheroid, which, of course, it never actually is. The correlation between this measure of capacity and the actually determined weight is almost perfect. In fact, the greater part of the difference between the determined coefficient of $+0.9804$ and that

for absolutely perfect correlation +1.0000 may be regarded as due to experimental errors either in the weighing or in calculating the bulk with only two decimal places in the observed length and breadth.

It is perfectly clear that the calculated bulk is a very excellent *relative* measure of the volume of an egg. It is another question as to how closely this measure approximates the *absolute* volume. It is clear that if the calculated bulk is a good absolute measure of the volume the specific gravity calculated from the mean weight and mean bulk ought to equal the actually observed mean specific gravity of eggs, since—

$$\text{Specific gravity} = \frac{\text{Weight in grams}}{\text{Volume in cubic centimeters}}$$

Substituting the means for weight and bulk given in Table 2, we have—

$$\text{Specific gravity} = \frac{55.264}{51.880} = 1.0652$$

The average specific gravity of fresh hen's eggs as determined by Wheeler at the New York Agricultural Experiment Station[1] was 1.090.

Since there is a considerable discrepancy here, it was thought advisable to make a series of determinations of the specific gravity of eggs from the same strain that furnished the material of Series A of this bulletin. This was done, with the results shown in Tables 15 and 16. Table 15 gives the frequency distribution for variation in the specific gravity of 61 Barred Plymouth Rock eggs. Each one of these eggs was laid by a different bird. The determinations were made within a few hours of the time of laying.

TABLE 15.—*Frequency distribution for the variation in the specific gravity of fresh eggs.*

[Data from Barred Plymouth Rocks.]

Specific gravity.	Frequency.	Specific gravity.	Frequency.
1.075–1.079	4	1.095–1.099	4
1.080–1.084	6	1.100–1.104	3
1.085–1.089	19		
1.090–1.094	25	Total	61

The chief variation constants for this distribution are shown in Table 16.

TABLE 16.—*Constants for variation of eggs in specific gravity.*

Constant.	Value.
Mean	1.0898±0.0005
Standard deviation	.0054± .0003
Coefficient of variation	.499

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[1] New York Agr. Exp. Sta., Seventh Ann. Rept., p. 67, 1889.

From these tables we note:

1. There is an extremely small degree of variation in respect to specific gravity among different eggs of an approximately equal freshness.

2. The mean value for the specific gravity of the egg obtained in this series of observations differs by only 0.0002 from that found by Wheeler.

3. The difference between the observed mean specific gravity of the egg and that determined from the calculated bulk and the weight is 0.0246. This difference is approximately 50 times the probable error of the observed mean.

It is plain that the calculated bulk on the average somewhat overestimates the absolute volume of the egg. Since both the mean weight and the mean specific gravity have been directly determined from the eggs, with small probable errors, it is possible to make a rather close determination of the average amount by which the bulk formula as here used overestimates the true volume of the egg. We have

$$\text{Mean volume} = \frac{55.264}{1.0898} = 50.710$$

The mean bulk determined from the frequency distribution is 51.880. It is then seen that on the average the calculated bulk overestimates the volume of the egg by 1.170 cubic centimeters. In other words, by assuming the egg to be a perfect prolate spheroid an average error of about 2.2 per cent is made in the calculation of the volume of the egg. This error is in excess. Evidently, then, the formula for bulk used in this paper not only gives an excellent relative measure of the volume of the egg, but also makes a fair absolute determination of this quantity, certainly sufficiently accurate for all practical purposes.

If still greater accuracy is desired it may be obtained by applying a correction factor, based on the calculated bulk. The determination of the volume of the egg would then take this form:

$$\text{Approximate volume of egg} = \{4.1888\ (\tfrac{1}{2}\text{ breadth})^2 \times (\tfrac{1}{2}\text{ length})\} - 0.022\{4.1888\ (\tfrac{1}{2}\text{ breadth})^2 \times (\tfrac{1}{2}\text{ length})\}$$

INDEX CORRELATIONS.

Before entering on the general discussion of the results of this section it is necessary to consider the two coefficients measuring the correlation of index with length and index with breadth, respectively. It was stated earlier that these index correlations would be calculated by formulæ. Pearson[1] has shown that if we have two indices $\frac{x_1}{x_3}$ and $\frac{x_2}{x_4}$ the gross correlation ρ between these indices will be

$$\rho = \frac{r_{12}v_1v_2 - r_{14}v_1v_4 - r_{23}v_2v_3 + r_{34}v_3v_4}{\sqrt{v_1^2 + v_3^2 - 2r_{13}v_1v_3}\ \sqrt{v_2^2 + v_4^2 - 2r_{24}v_2v_4}}$$

where r_{12}----r_{34} represent the calculated coefficients of correlation and v_1----v_4 the coefficients of variation of the variables of x_1----x_4, respectively.

It has further been pointed out by Pearl[2] that the gross correlation ρ between the length-breadth index $\frac{x_1}{x_3}$ and the breadth x_1 is

$$\rho = \frac{v_3 - r_{13}v_3}{\sqrt{v_1^2 + v_3^2 - 2r_{13}v_1v_3}} \text{------------------} \text{(i)}$$

Between the index $\frac{x_1}{x_3}$ and the length x_3 the gross correlation is

$$\rho = \frac{r_{13}v_1 - v_3}{\sqrt{v_1^2 + v_3^2 - 2r_{13}v_1v_3}} \text{------------------} \text{(ii)}$$

In the above-mentioned memoir Pearson showed that a large portion of the gross correlation when an index is correlated either with another index or with one of the actual measurements which enter into the index is not due to organic relationship, but is a spurious correlation arising from arithmetical reasons. It has been shown that the measure of this spurious correlation ρ_0 in the case of index-breadth is

$$\rho_0 = \frac{v_3}{\sqrt{v_1^2 + v_3^2}} \text{------------------} \text{(iii)}$$

Similarly for index-length correlation

$$\rho_0 = \frac{-v_3}{\sqrt{v_1^2 + v_3^2}} \text{------------------} \text{(iv)}$$

In Table 17 are given first the gross correlations, ρ, between index and length and index and breadth as calculated from (i) and (ii). Next are given the corresponding spurious correlations calculated from (iii) and (iv). Finally are given the net correlations $\rho - \rho_0$. These represent the part of the gross correlations that may be considered to be due to true organic interrelationship. If the indices were arbitrarily made up from a random series of measurements of the lengths and breadths of different eggs the values in the last column, $\rho-\rho_0$, would be significantly zero. The meaning of the expression $\rho-\rho_0$ had been fully discussed by Pearl (*loc. cit.*) and need not be repeated here. Expressed in terms of regression, it indicates the amount of shift of the gross regression line beyond the spurious line. This shift is due to the organic correlation. The probable errors given in the spurious and net columns are calculated from the formula $\text{P.E.}_r = 0.67449\frac{1-r^2}{\sqrt{n}}$. This assumes that r has been calculated from the usual formula $r=\frac{S(xy)}{N\sigma_1\sigma_2}$. The error involved in this assumption is probably not significant.

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[1] Pearson, K. On a form of spurious correlation which may arise when indices are used in the measurement of organs. Proc. Roy. Soc., vol. 60, pp. 489–498, 1897.

[2] Pearl, R. A Biometrical Study of Conjugation in Paramecium. Biometrika, vol. V, pp. 213–297, 1907.

Table 17.—*Index correlations.*

Characters.	Gross, ρ	Spurious, ρ_0	Net, $\rho-\rho_0$
Index-length	-0.7707	-0.7901 ± 0.0119	$+0.0194\pm0.0318$
Index-breadth	$+\ .7552$	$+\ .7901\pm\ .0119$	$-\ .0349\pm\ .0318$

From an examination of the last column of this table it is clear that there is no significant correlation between the shape of an egg as measured by the length-breadth index and either its length or breadth. In neither case is the net correlation significantly greater than its probable error.

In discussing the correlation between the index and volume (p. 195), it was said that there also the values of r were not significant, taken independently. From the fact that both the index-bulk and index-weight correlations were positive and of values bordering on significance, it was concluded that there might be some slight correlation between shape and capacity variation of the egg. With the additional evidence afforded by Table 17 it becomes still more certain that if there is any real correlation between size and shape characters of the egg it must be extremely slight in amount or degree.

COMPARISON OF CORRELATION IN THE EGG AND THE SKULL.

Earlier in this bulletin it has been shown that the egg and the human skull show a marked similarity in respect to variation in corresponding dimensions. It was suggested that this correspondence between two such dissimilar things probably owes its origin to the fact that the developmental mechanical forces which come into play in determining the form of an egg are essentially of the same kind as those which give the skull its definitive form. If this view of the matter is correct it would be expected that a similar correspondence would be found in respect to the degree of correlation between the different dimensions in the two objects. As a matter of fact, such is the case, as is shown by the data given in Table 18.

In this table are collected from the literature correlation coefficients for skull dimensions in several human races and also in the albino rat. In the case of the human data only the constants for males are tabled, in order to save space and at the same time avoid the mental confusion which arises with a long series of constants, all showing about the same thing, but differing slightly among themselves. Nothing different in principle would be brought out if all the constants for females were given in the table. In obtaining the means the individual coefficients have been weighted in proportion to the number of cases on which they were based.

TABLE 18.—*Comparison of correlations in egg and skull characters.*

Characters and race.	Number of cases.	Coefficient of correlation.	
Skull length and breadth:			
French males[1]	860	0.089±0.024	
German males[2]	100	.286± .062	
English males[3]	131	.240± .065	
Naqada males[1]	139	.344± .050	
Weighted mean, human males	1,230	*0.150*	
Albino rat[4]	53	♂=0.665±0.052	
	51	♀=0.397± .080	
Egg length and breadth	450	*0.084± .032*	
Skull length and capacity:			
English males[3]	72	0.597±0.051	
Naqada males[1]	89	.501± .054	
German males[2]	100	.515± .050	
Weighted mean, human males	261	*0.533*	
Albino rat[4]	53	♂=0.761±0.039	
	51	♀=0.577± .062	
Egg length and weight	450	*0.580± .021*	
Egg length and bulk	450	*.575± .021*	
Skull breadth and capacity:			
English males[3]	72	0.631±0.048	
Naqada males[1]	89	.434± .058	
German males[2]	100	.672± .037	
Weighted mean, human males	261	*0.580*	
Albino rat[4]	53	♂=0.838±0.028	
	51	♀=0.632± .057	
Egg breadth and weight	450	*0.836± .010*	
Egg breadth and bulk	450	*.860± .008*	
Skull B/L index and length:		*Gross.*	*Spurious.*
English males[3]	131	−0.547±0.041	−0.658±0.033
French males[1]	860	− .652± .014	− .686± .013
Naqada males[1]	130	− .551± .041	− .694± .031
Weighted mean, human males	1,121	*−0.628*	*−0.684*
Egg B/L index and length	450	*− .771*	*− .790± .012*
Skull B/L index and length, *net* correlation (mean)	....	*+0.056*	
Egg B/L index and length, *net* correlation	....	*+0.019±0.032*	
Skull B/L index and breadth:			
English males[3]	131	0.682±0.032	0.753±0.026
French males[1]	860	.699± .012	.727± .011
Naqada males[1]	130	.594± .038	.720± .028
Weighted mean, human males	1,121	*0.685*	*0.729*
Egg B/L index and breadth	450	*.755*	*.790± .012*
Skull B/L index and breadth, net correlation (mean)	....	*−0.044*	
Egg B/L index and breadth, net correlation	....	*−0.055±0.032*	

[1] Fawcett, C. D. Biometrika, Vol. I, p. 457.
[2] Lee, A. Phil. Trans, Vol. 196A, p. 231.
[3] Macdonell, W. R. Biometrika, Vol. III, p. 233.
[4] Hatai, S. Amer. Jour. Anat., Vol. VII, p. 432.

From this table it is at once apparent that the same general correspondence between the egg and the skull, which was found to hold for relative variability, also obtains with reference to the degree of correlation in variation. Taking the various points seriatim, we note:

1. That while the correlation between length and breadth in the human skull tends to be higher than that for the corresponding egg dimensions, yet taking the mean for all the coefficients it is not greatly so. The coefficient for skull length and skull breadth in the French series (the most extensive of all) is almost identical with that for the corresponding dimensions of the egg. In the case of the rat skull the correlations are distinctly higher than for either human skull or egg. But here two facts must be taken into account. In the first place the rat series are small and may be comparatively "bad" samples of the general population of rat skulls. The unusually large differences between the constants for the male and the female series suggests that such may be the case. In the second place, the relative influence of the two morphogenetic factors chiefly concerned here (tension of temporal muscles and internal pressure from developing brain) must be distinctly different in the case of the rat's skull, with its proportionately small brain and almost no vaulting, its comparatively heavy jaw with associated muscular development, and its entirely different facial development, from what obtains in the case of the human skull. In other words, there is not the same morphogenetic basis for the comparison of the rat's skull with the bird's egg that there is for comparing the human skull with this object.

2. That the agreement between human skull and egg in respect to the correlation between length and capacity is very close. This is true whether weight or volume be taken as the capacity measure in the case of the egg.

3. That this accord between egg and skull is not quite so close in the case of the breadth-capacity correlation as for the length-capacity correlation. Here there is closer agreement between the rat skull and the egg. The most significant point, however, is that all the cases (rat skull, human skull, etc., and egg) agree in showing a somewhat closer correlation between breadth and capacity than between length and capacity. This difference is least for the human skull and greatest for the egg, but it is in the same sense for all three forms.

4. That in respect to index correlations—shape with size—there is a remarkably close agreement between egg and skull. The net organic correlations are, within the limits of error of random sampling, identical.

Taking all the facts together it may fairly be said that in respect to relative variability and correlation of dimensions there is a close similarity between the hen's egg and the human skull in particular, and probably to a lesser extent the mammalian skull in general.

The most probable explanation of this similarity is to be found in the fact that the immediate physical and mechanical forces which have to do with the determination of the definitive form in the two cases are of essentially the same kind, and act in essentially the same way.

REGRESSION AND THE DETERMINATION OF THE PROBABLE VALUE OF A PARTICULAR EGG DIMENSION FROM A KNOWLEDGE OF OTHER DIMENSIONS.

One of the aims of science is to be able to predict the occurrence or attributes of one phenomenon from a knowledge of other related phenomena. It is clear that it would be of advantage in many ways if one could express with reasonable accuracy certain of the physical characteristics of eggs in terms of other characters. For example, it often happens that one is able to obtain directly the measurements of an egg but not its weight. This is the case with "blown" eggs in a museum. Further, in eggs which have been stored in such a way that they have lost water by evaporation it is impossible to obtain the correct weight directly, though their linear dimensions will not have changed. In such cases formulæ to determine the probable mean fresh weight of a series of such eggs would be valuable. Practical use might possibly be made of such formulæ in the investigation of cold-storage eggs. In the following pages especial attention will be given to the derivation of formulæ for estimating the weight and volume of eggs from the direct measurements of length and breadth.

For such characters as are capable of numerical expression the simplest method of predicting one character in terms of another is furnished by the principle of regression.

The degree of accuracy with which such a prediction can be made depends upon two things; namely, (a) the relation between the characters considered, i. e., the degree of correlation, and (b) the variability of the characters. It is well known that if from the ordinary correlation table the means of the arrays for either correlated character are plotted the points so obtained usually lie very nearly on a straight line. By determining the equation of the straight line best fitting these points it is clear that we obtain an expression of one of the characters in terms of the other. Occasionally, however, it happens that the plotted means do not lie in a straight line. In such cases the regression is said to be "nonlinear," and the correlation "skew." Some curve must then be found to graduate the means of the arrays.

Before entering upon the detailed discussion of the regression lines for egg characters it will be of advantage to consider briefly certain points of mathematical theory regarding tests for linearity of regression.

LINEARITY OF REGRESSION.

In his memoir on "Skew Correlation and Non-Linear Regression,"[1] Pearson has pointed out a method of measuring the approach to linearity of the regression curve. In addition to the coefficient of correlation, *r*, the two most significant constants are (a) the square root of the mean square deviation of the means of the arrays from the regression line Σ_M, and (b) the correlation ratio, η. The latter gives the mean reduction in the variability of an array as compared with that of the whole population. It is evident that

$$\eta = \frac{\sigma_{my}}{\sigma_y} \text{ - (i)}$$

where σ_{my} is the standard deviation of the weighted means of the *y* arrays about the mean of the population, and σ_y is the standard deviation of the variates about the same mean. In calculating σ_{my} the squared deviations of means are weighted with their frequencies. Pearson has further pointed out that

$$\Sigma_M^2 = \sigma_{my}^2 - r\sigma_y^2 \text{ - (ii)}$$

Hence from (i) and (ii)

$$\Sigma_M = \sigma_y\sqrt{\eta^2 - r^2}$$

If the regression is linear, Σ_M should equal zero and η should equal *r* within the limits of random sampling. Table 19 gives the values of Σ_m and η derived from the data in the correlation tables (pp. 192–193). The correlation coefficients for length with breadth and for the index correlations were so low that it was not deemed worth while to consider their regression equations.

Also from the inspection of Table 13 and particularly from an examination of figures 10 and 11 (p. 209) it is clear that the regressions of weight on bulk and of bulk on weight are essentially linear. Hence, we have not gone to the trouble of calculating the constants for the linearity of regression in these cases.

For convenience there is included in Table 19 the values of *r* and the corresponding differences with their probable errors. It has been shown by Pearson (*loc. cit.*) that a very close approximation to the probable error of η is given by the formula

$$P.E._\eta = 0.67449\frac{1-\eta^2}{\sqrt{N}}$$

Blakeman[2] has given approximate formulæ for the probable errors of $\eta - r^2$ and $\eta - r$.

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[1] Pearson, K. Mathematical Contributions to the Theory of Evolution XIV. Draper's Company Research Memoirs, Biometric Series II, 1905.

[2] Blakeman, J. On Tests for Linearity of Regression in Frequency Distributions. Biometrika, Vol. IV, pp. 332-350, 1905.

His formulæ have been used in obtaining the probable errors of these constants.

TABLE 19.—*Analytical constants for linearity of regression.*

Correlated characters.	r	η[1]	$\eta-r$	Σ_M	η^2-r^2
Bulk and length............	0.5751 ± 0.0213	0.6163 ± 0.0197	0.0412 ± 0.0116	0.2214σ	0.0490 ± 0.0136
Weight and length..........	.5797 ± .0211	.6127 ± .0198	.0330 ± .0113	.1963σ	.0393 ± .0133
Weight and breadth.........	.8357 ± .0096	.8377 ± .0095	.0020 ± .0022	.0582σ	.0034 ± .0037
Bulk and breadth...........	.8602 ± .0083	.8620 ± .0082	.0018 ± .0021	.0563σ	.0032 ± .0036

[1] Calculated from the weighted squared deviations of the means from the mean of the population. Sheppard's corrections were *not* used.

From Table 19 we note that in the regression of bulk on length and weight on length the values of $\eta-r$ and η^2-r^2 are more than three times their probable errors. In these cases η is significantly greater than r. Likewise Σ_M deviates sensibly from zero. Judged by this test we must conclude that the regressions of bulk and weight on length deviate sensibly from linearity.

Turning to the regression of bulk on breadth and weight on breadth we note that the values $\eta-r$ and η^2-r^2 are just about equal to their probable errors. Hence, η does not differ significantly from r. From this we may conclude that the best fitting straight line will give as good results in the prediction of weight or bulk from breadth as any other curve.

The deviation of r from η and of Σ_M from zero necessarily implies departure from linearity. This may be due to either one or both of two causes. Either the points determined by the means do not lie in a straight line and can be better described by some other curve, or else the points deviate from a straight line but nevertheless can be better described by that than by any other curve. In order to decide in which class the present series lies we may have recourse to the diagrams showing the plotted means of the arrays.

SIMPLE LINEAR REGRESSION.

Before taking up these diagrams, however, it will be of advantage to have before us the equations to the respective regression lines, and these may then be plotted on the same figure. It has been shown by Yule[1] and others that the simplest forms of the characteristics or regression equations with two variables are

$$x=r\frac{\sigma_1}{\sigma_2}y \quad \text{(i)}$$

and

$$y=r\frac{\sigma_2}{\sigma_1}x \quad \text{(ii)}$$

where x and y represent deviations from their respective mean values; σ_1 and σ_2 are the standard deviations of X and Y respectively; and r is their coefficient of correlation as usual.

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[1] Yule, G. U. On the Theory of Correlation. Jour. Roy. Stat. Soc., Vol. LX, 1897.

Transferring these values to their means we have

$$(X - \text{mean } x) = r\frac{\sigma_1}{\sigma_2}(Y - \text{mean } y) \text{ . . . . (iii)}$$

$$(Y - \text{mean } y) = r\frac{\sigma_2}{\sigma_1}(X - \text{mean } x) \text{ . . . . (iv)}$$

The expressions $r\frac{\sigma_1}{\sigma_2}$ and $r\frac{\sigma_2}{\sigma_1}$ are spoken of as the regression coefficients and often designated as b_1 and b_2, respectively.

Further it is evident from the mathematical relations involved that the standard error, Σ, made in estimating X from equation (iii) is $\sigma_1\sqrt{1-r^2}$. Similarly $\sigma_2\sqrt{1-r^2}$ is the probable error of Y as estimated from equation (iv).

Now applying these equations to the data in hand we obtain the following regression equations together with their standard errors. Only those equations are given in which weight or bulk is estimated from other characters.

The abbreviations used are evident; *W.* = Weight; *L.* = Length; *Br.* = Breadth; *Blk.* = Bulk.

(1) $W. = 1.1229L. - 7.9792$; $\Sigma = 3.7661$.
(2) $W. = 2.8035Br. - 62.2483$; $\Sigma = 2.5383$.
(3) $W. = 1.0704Blk. - 0.2681$; $\Sigma = 0.9610$.
(4) $Blk. = 1.0203L. - 5.5879$; $\Sigma = 3.4631$.
(5) $Blk. = 2.6431Br. - 58.9081$; $\Sigma = 2.1591$.
(6) $Blk. = 0.8979W. + 2.2563$; $\Sigma = 0.8344$.

Since there is a very high correlation between weight and bulk the corresponding regression lines for weight and for bulk on length, as well as for weight and bulk on breadth, show a striking similarity. The regression lines for weight on bulk and bulk on weight are practically identical. For this reason we may discuss these regressions in pairs, taking first those in which the length forms are variable. These are exhibited in figures 6 and 7.

From these figures it is clear that the regressions of weight on length and of bulk on length follow some other law than that of the straight line. The deviations at either extremity are in both cases definitely directed and can not be accounted for as random deviations. This furnishes confirmatory evidence concerning the conclusions drawn from a study of the correlation ratio. We are undoubtedly dealing with nonlinear regression in these cases. The figures show that the fitted regression line represents the facts well in the middle of the range, but prediction as to the weight or bulk of very long or very short eggs made according to these equations would vary rather widely from the true values. However, in a random sample of eggs the majority will lie in that portion of the curve which is well graduated by the regression line. Thus in the above figures 6 and 7 it is evident that the points at which the line of the plotted means begins to deviate sensibly from the fitted line may be taken as corresponding approximately to egg lengths of 51 and 61 mm. Referring to the frequency distribution for length (Table 1), it is seen that 433 eggs out of the total 450 eggs measured have lengths between 51 mm. and 61 mm. In other words, over 96 per cent of the eggs in this sample fall within that portion of the curve which is satisfactorily fitted by the regression straight line. It may further be noted that these points of 51 mm. and 61 mm. lie on either side of the mean length at distances nearly equal to -2σ and $+2\sigma$, respectively. It is thus clear that for any random sample of eggs having a mean length and a standard deviation in length approximately the same as those of the present distribution one will get for over 96 per cent of the eggs fairly good predictions of weight and bulk from equations (1) and (4). If the regression line will estimate the weight or volume of 96 per cent of the eggs as closely as can be done by any equation which takes account of the length only, we may expect to get fairly good results when the equation is applied to a random sample of eggs.

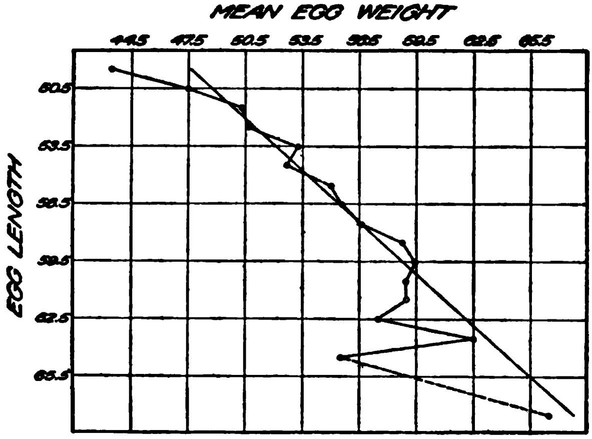

FIG. 6.—Regression of egg weight on egg length.

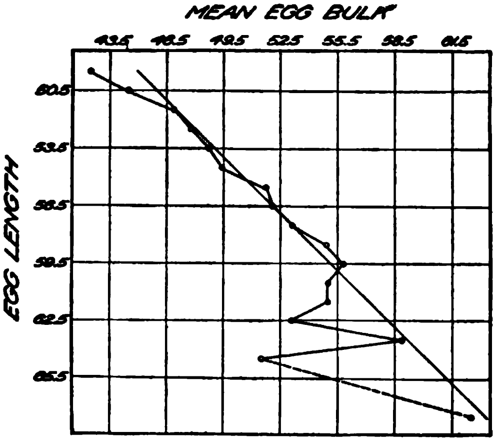

FIG. 7 —Regression of egg bulk on egg length.

Such a test for this and other equations will be made in a later section of this bulletin (p. 223).

A still further test as to the estimation of such equations is given by the standard error $\Sigma = \sigma\sqrt{1-r^2}$. The value for each case is given with the equations. In the regression of weight on length

$\Sigma = 3.7661$ and for bulk on length $\Sigma = 3.4631$. In other words, the standard error of the weight as predicted by equation (1) is about 3.8 grams, or about 7 per cent of the mean weight.

We may next consider the regressions in which weight and bulk are associated with breadth. The equations to the fitted lines are given as (2) and (5) on page 206. The graphs of these lines, together with the plotted means, are given in figures 8 and 9.

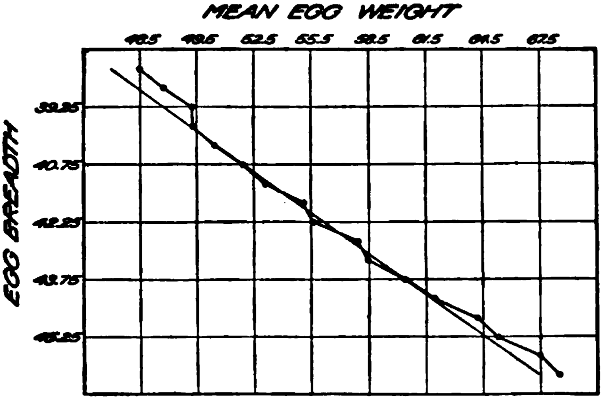

FIG. 8.—Regression of egg weight on egg breadth.

It is at once evident that here the regression lines fit the data much better than in figures 6 and 7. However, there is here also an evident deviation from linearity at the ends of the curves. Looking at the line of plotted means it appears clearly probable that one could fit them better with a parabola than with a straight line. In these cases the results of inspection apparently do not confirm the conclusion drawn from a study of the correlation ratio (p. 205). It was there concluded that, since the value of $\eta - r$ was no greater than its probable error, these regressions could be considered as essentially linear. The reason for this discrepancy is that both η and r are calculated from the ordinates weighted with their frequency. For this reason the regression lines fit the middle portions of the curves very well indeed. Further, the deviations at the ends are not great in magnitude, and the total frequency in these regions is very small.

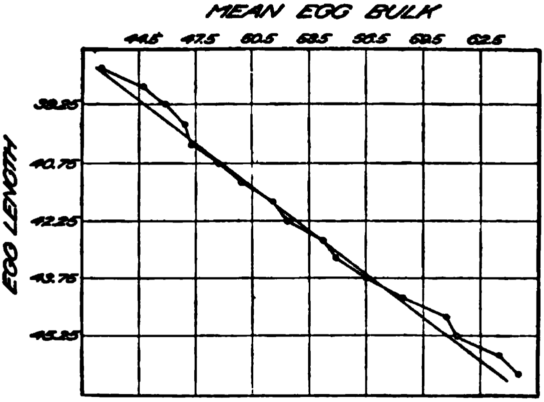

FIG. 9.—Regression of egg bulk on egg breadth.

If, as in the case of capacity with length, the points where the curves begin to deviate sensibly from the fitted line are examined, it is found that these correspond, taking the two curves together, to breadths of about 39.50 mm. and 45 mm. Referring to the frequency distribution for breadth (Table 1), it is seen that 427 out of the 450 eggs are included between these limits. In other words, the regression line fits with considerable accuracy about 95 per cent of the eggs. While the deviations at either end are not very great, nevertheless the data from the present sample of eggs can be somewhat more closely described by a parabola than by a straight line, as will be shown later.

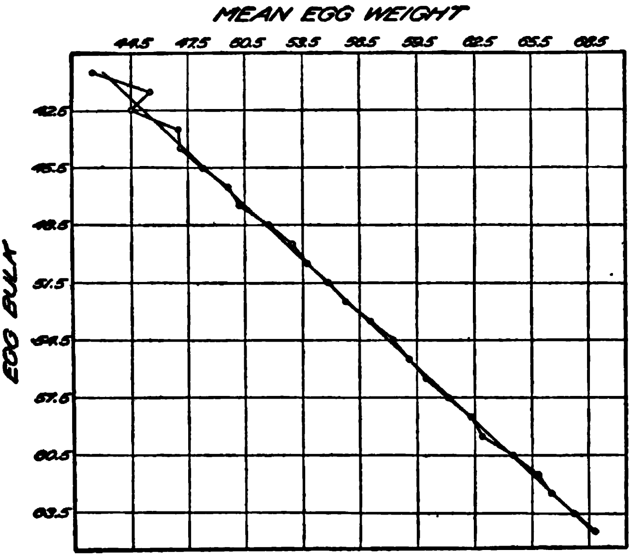

FIG. 10.—Regression of egg weight on egg bulk.

The standard error made in estimating the capacity of an egg from its breadth is in the case of the weight 2.5383 grams and in the case of the bulk 2.1519 grams. Thus the average estimation of capacity is more than 1 gram closer when made from the breadth rather than from the length as the second variable.

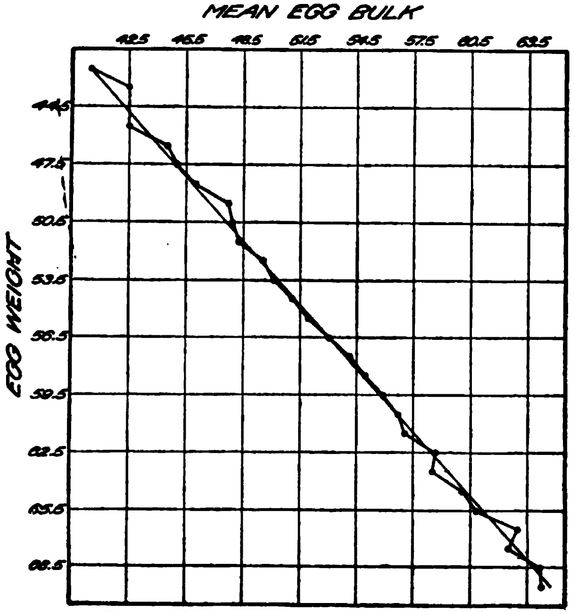

FIG. 11.—Regression of egg bulk on egg weight.

The regressions of weight on bulk and of bulk on weight may next be considered. The equations to these regression lines are given as equations (3) and (6) on page 206. Figures 10 and 11 show the graphs of these equations along with the plotted means.

The diagrams afford sufficient proof of the strict linearity of these regressions, without further demonstration. It would clearly be impossible to get any curve which would estimate weight from bulk or bulk from weight better than the present straight lines. Further, since the correlation coefficient between these two characters has such a high value, it is to be expected that the absolute estimation would be very close in each case. Judging from the above diagrams, this would certainly seem to be the case. However, it must be remembered that the regression line might fit the plotted means very closely, and yet if the standard deviations of the characters are large the standard error of the estimation would be correspondingly large. Here, however, this is not the case. The standard error of equation (3) is 0.9610, and for equation (6) is 0.8344. Taking the case of the weight on bulk (equation 3) we note that the error of 0.96 gram is only about 1.7 per cent of the mean egg weight. In the case of bulk on weight the estimation is made with a standard error of less than 1.5 per cent of the mean bulk.

PARABOLIC REGRESSION.

CAPACITY-LENGTH REGRESSIONS.

It has been shown above (pp. 205) that the regressions of egg weight and bulk on length are nonlinear. In such cases the problem of obtaining the best fitting curve for the graduation of the observed regression line is greatly complicated. In his previously mentioned work on "Skew Correlation and Non-Linear Regression" Pearson has developed the theory of higher types of regression. He classifies these types as linear, parabolic, cubic, and quartic, corresponding respectively to the straight line, second, third, and fourth order parabolas. As a first approach to fitting these regression curves we have used Pearson's parabolic type.

The general form for this type of equation is

$$y_{xp} = a_0 + a_1 x_p + a_2 x_p^2$$

where y_{xp} is the mean of an x-array of y's.

Evaluating the a's in terms of the correlation and variation constants and subsequently simplifying the equation, Pearson arrives at the following expression for parabolic regression:

$$\frac{y_{xp}}{\sigma_y} = r\frac{x_p}{\sigma_x} \pm \sqrt{\frac{\eta^2 - r^2}{\phi_2}}\left\{\left(\frac{x_p}{\sigma_x}\right)^2 - \sqrt{\beta_1}\left(\frac{x_p}{\sigma_x}\right) - 1\right\}$$

where y_{xp} is the deviation from the mean of the y-arrays corresponding to the given deviation from the x-arrays, viz, x_p; η and r are the correlation ratio and correlation coefficient respectively; and σ_x and σ_y the standard deviations. $\phi_2 = \beta_2 - \beta_1 - 1$.

The values of β_1 and β_2 and $\sqrt{\beta_1}$ are given in Table 5. Except in the case of very nearly linear regression there will be no doubt as to the sign of $\sqrt{\eta^2 - r^2}$.

Inspection will tell whether the parabola is concave or convex to the x axis.

Applying this formula to the capacity-length regressions, we get for weight on length,

$$y_{xp} = 1.2601x_p - 0.0931x_p^2 + 0.5299$$

and for bulk on length,

$$y_{xp} = 1.1607x_p - 0.0952x_p^2 + 0.5420$$

It was found upon trial of these curves that the fit was not good. The graduation toward the upper ends of the curves was particularly bad. Through the middle and over a portion of the lower end the curves represented the facts fairly well. However, at the lower end of the curves the fit was again bad. It is unlikely that either the weight or bulk of eggs over 64 mm. in length decreases at anything like the rate shown by these theoretical curves. It is to be remembered that the curves under discussion are second order parabolas fitted to the weighted means of the arrays. As has been pointed out in the case of the simple regression lines (p. 209), the frequencies at the two ends are very small. The curves attempt to fit the heavily weighted ordinates at the middle of the curve and let the ends take care of themselves.

It is of course possible that Pearson's cubic or quartic regression curves might graduate these data more satisfactorily. However, because of the very considerable probable errors connected with the use of the higher moments, it did not seem worth while to calculate these equations. Instead the attempt has been made to graduate the data with parabolas using the unweighted means.

Such parabolas can be fitted either by the method of least squares commonly used by physicists, or by Pearson's[1] method of moments. Where a series of parabolas of different orders are to be fitted to the same data the method of moments offers many advantages. This latter method has been used in the present instance.

The general equation to these parabolas is

$$y = e_0 + e_1x + e_2x^2 + \ldots\ldots e_{n-1}x^{n-1}$$

where e_0, e_1, e_2, etc., are constants to be determined from the data.

Parabolas of the first, second, third, fourth, fifth, and sixth orders have been fitted to both the regression of weight on length and of bulk on length. This makes 12 parabolas in all.

---

[1] Pearson, K. On the Systematic Fitting of Curves to Observation and Measurements. Biometrika, Vol. I, p. 265, and Vol. II, p. 1, 1902 and 1903.

The equations to the parabolas graduating the regression of weight on length are as follows:

Straight line—

$$y=56.1367\left(1+0.1328\frac{x}{l}\right)$$

Second order parabola—

$$y=56.1367\left\{1.0218+0.1328\frac{x}{l}-0.0654\left(\frac{x}{l}\right)^2\right\}$$

Third order parabola—

$$y=56.1367\left\{1.0218+0.0724\frac{x}{l}-0.0654\left(\frac{x}{l}\right)^2+0.1007\left(\frac{x}{l}\right)^3\right\}$$

Fourth order parabola—

$$y=56.1367\left\{1.0256+0.0724\left(\frac{x}{l}\right)-0.1037\left(\frac{x}{l}\right)^2+0.1007\left(\frac{x}{l}\right)^3+0.0447\left(\frac{x}{l}\right)^4\right\}$$

Fifth order parabola—

$$y=56.1367\left\{1.0256+0.1274\frac{x}{l}-0.1037\left(\frac{x}{l}\right)^2 -0.1562\left(\frac{x}{l}\right)^3+0.0447\left(\frac{x}{l}\right)^4+0.2312\left(\frac{x}{l}\right)^5\right\}$$

Sixth order parabola—

$$y=56.1367\left\{1.0870+0.1274\frac{x}{l}-1.3925\left(\frac{x}{l}\right)^2-0.1562\left(\frac{x}{l}\right)^3 +3.9112\left(\frac{x}{l}\right)^4+0.2312\left(\frac{x}{l}\right)^5-2.8354\left(\frac{x}{l}\right)^6\right\}$$

In these equations l is equal to one-half the range, or 9 in the present instance, while x is the distance in units from the origin of the curve, which is at the middle of the range.

The equations of the parabolas fitted to the regression of bulk on length are as follows:

Straight line—

$$y=52.5044\left(1+0.1288\frac{x}{l}\right)$$

Second order parabola—

$$y=52.5044\left\{1.0203+0.1288\left(\frac{x}{l}\right)-0.0610\left(\frac{x}{l}\right)^2\right\}$$

Third order parabola—

$$y=52.5044\left\{1.0203+0.0718\left(\frac{x}{l}\right)-0.0610\left(\frac{x}{l}\right)^2+0.0926\left(\frac{x}{l}\right)^3\right\}$$

Fourth order parabola—

$$y=52.5044\left\{1.0287+0.0718\left(\frac{x}{l}\right)-0.1450\left(\frac{x}{l}\right)^2+0.0926\left(\frac{x}{l}\right)^3+0.0980\left(\frac{x}{l}\right)^4\right\}$$

Fifth order parabola—

$$y=52.5044\left\{1.0287+0.1169\frac{x}{l}-0.1450\left(\frac{x}{l}\right)^2 -0.1114\left(\frac{x}{l}\right)^3+0.0980\left(\frac{x}{l}\right)^4+0.1836\left(\frac{x}{l}\right)^5\right\}$$

Sixth order parabola—

$$y=52.5044\left\{1.0904+0.1169\frac{x}{l}+1.2305\left(\frac{x}{l}\right)^2-0.1114\left(\frac{x}{l}\right)^3 +13.5352\left(\frac{x}{l}\right)^4+0.1836\left(\frac{x}{l}\right)^5+11.7305\left(\frac{x}{l}\right)^6\right\}$$

Upon plotting out these curves against the observations it was found that results which must be considered on the whole as excellent were obtained with certain of the higher order parabolas. Others gave bad results owing to having too many points of inflection. In these cases while the curve came close to the individual observations the result could not be considered a real graduation. On the whole the third, fourth, and fifth order parabolas gave the best results. Accordingly these have been chosen for graphical representation in figures 12 and 13.

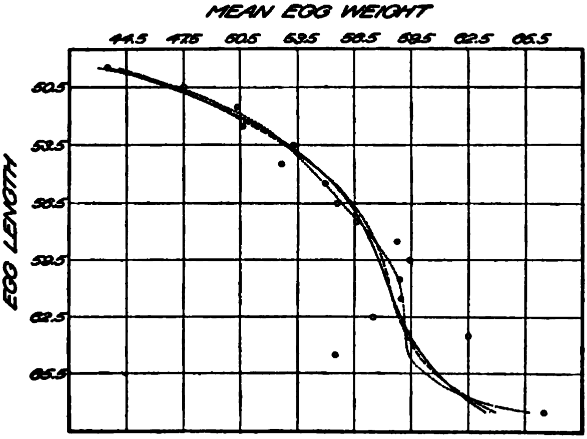

FIG. 12.—Regression of egg weight on egg length. The zigzag line gives the observations; ——— third order parabola; — — — fourth order parabola; …… fifth order parabola.

CAPACITY-BREADTH REGRESSION.

As has been pointed out in a previous section (*cf.* p. 208), the regressions of weight on breadth and of bulk on breadth are fitted fairly well by the ordinary regression line. According to the test for linearity these regressions do not deviate sensibly from the straight line. However, inspection of the actual observations shows that toward the ends there is a marked tendency for the regression line to turn downward. It must be remembered here again that both in the test for linearity and in the actual fitting of the ordinary regression line weighted lines are used. Since in these cases the weight is mostly toward the middle of the curve, the points toward the end have little influence. Owing to the constancy of these deviations in the same direction, however, it seemed possible that they possess some real significance, even though the test for linearity used failed to attribute any to them.

For these reasons it was decided to attempt to fit the unweighted ordinates with parabolas. In these calculations the method of least squares was used. Both the straight line and the second order parabola have been determined. It is to be remembered that these are fitted to the unweighted ordinates.

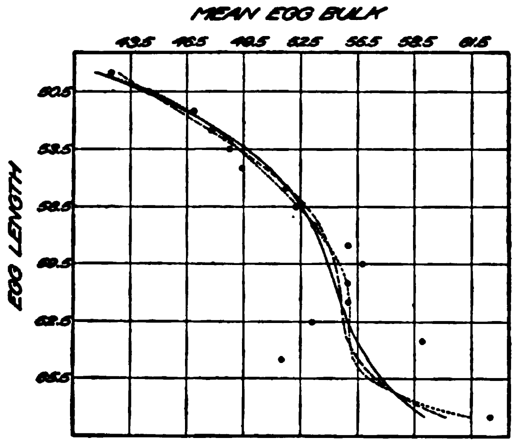

FIG. 13.—Regression of egg bulk on egg length. Significance of lines as in figure 12.

The equations to these lines are as follows:

Regression of weight on breadth:

Straight line—

$$Wt. = 2.793\ Br. - 61.345$$

Second order parabola—

$$Wt. = 0.111\ (Br.)^2 - 6.620\ Br. + 136.855$$

Regression of bulk on breadth:

Straight line—

$$Blk. = 2.692\ Br. - 60.558$$

Second order parabola—

$$Blk. = 0.043\ (Br.)^2 - 2.347\ Br. + 31.598$$

The observations and fitted lines are shown in figure.

It is evident from the diagrams that the graduations here are excellent, particularly those given by the parabolas.

MULTIPLE REGRESSION.

In the preceding section we have discussed the methods of estimating the probable magnitude of one character of an egg from a knowledge of the actual magnitude of another character. More satisfactory results can sometimes be obtained by using two or more characters from which to reach an estimation of the probable value of another. In taking up this phase of the subject we shall deal first with ordinary multiple regression, which assumes that all the simple regressions involved are linear. After that will be discussed parabolic multiple regression equations as applied to certain characters of the egg. No regressions involving more than three characters are discussed.

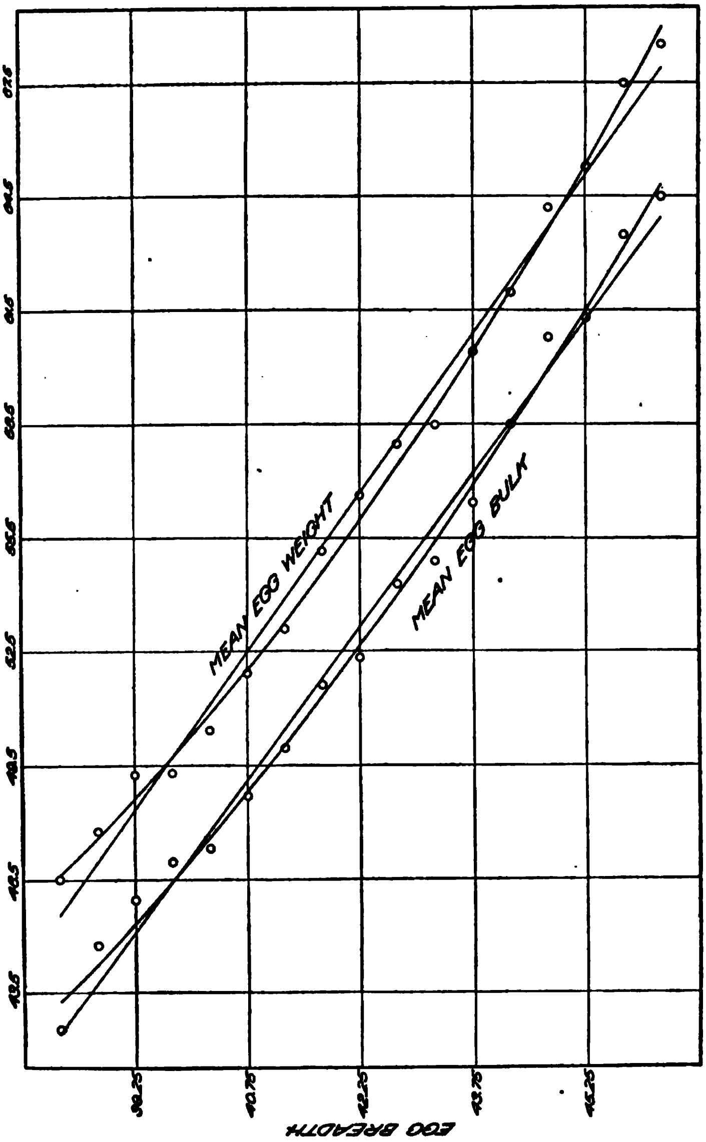

FIG. 14.—Showing the regression of weight of eggs on breadth (upper group) and the regression of bulk (volume) on breadth (lower group).

MULTIPLE LINEAR REGRESSION.

It has been shown by Yule[1] and others that the regression of x_1 on x_2 and x_3 may be represented by

$$x_1 = b_{12}x_2 + b_{13}x_3$$

where the coefficients b_{12} and b_{13} have the following values:

$$b_{12} = \frac{r_{12} - r_{13}r_{23}}{1 - r_{23}^2} \cdot \frac{\sigma_1}{\sigma_2}$$

$$b_{13} = \frac{r_{13} - r_{12}r_{23}}{1 - r_{23}^2} \cdot \frac{\sigma_1}{\sigma_3}$$

In these equations r_{12}, r_{13}, and r_{23} are the coefficients of correlation for the characters x_1, x_2, and x_3, and ς_1, ς_2 and ς_3 the standard deviations.

Further, the standard error of such a regression equation is given by

$$\Sigma_{12} = \sigma_1\sqrt{1 - R_1^2}$$

where

$$R_1^2 = \frac{r_{12}^2 + r_{13}^2 - 2r_{12}r_{13}r_{23}}{1 - r_{23}^2}$$

These equations have been used to determine the regression of weight and bulk on certain other characters. The following five regression equations have been deemed of sufficient importance to work out in detail. In a later section these equations, along with others, are tested as to their efficiency in estimating the several characters.

$$\begin{aligned}
Wt. &= 0.994Lt. + 2.660Br. - 112.217; \quad \Sigma = 0.924 \\
Wt. &= 0.046Lt. + 1.056Blk. - 2.081; \quad \Sigma = 0.907 \\
Wt. &= 1.098Blk. - 0.098Br. + 2.416; \quad \Sigma = 0.909 \\
Blk. &= 0.018Lt. + 0.893\,Wt. + 1.534; \quad \Sigma = 0.652 \\
Blk. &= 0.416Br. + 0.794\,Wt. - 9.463; \quad \Sigma = 0.773
\end{aligned}$$

In these equations *Wt.* denotes weight in grams; *Blk.* = bulk in cubic centimeters; *Lt.* = length in millimeters; and *Br.* = breadth in millimeters.

Considering the probable errors of these equations, as shown by Σ, it is clear that there is little choice between the three equations estimating weight in respect to the accuracy of the prediction. The equations in which the bulk is used as one factor have a slightly smaller error. In any case the error is about nine-tenths of a gram. This is roughly an error of 2 per cent in estimating the weight of an egg from dimensional characters.

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[1] Loc. cit.

In the case of the bulk the error is smaller when the length and weight are used as the basis of the prediction than when the breadth and weight are taken. In the former case the error is about 0.65 of a cubic centimeter, and in the latter about 0.77 of a cubic centimeter.

MULTIPLE PARABOLIC REGRESSION.

In the preceding section multiple regression equations have been determined on the assumption that the regression was linear for each character. We know, however, from previous determinations (*cf.* p. 205) that at least the regressions which involve the length of the egg as one factor are certainly not linear but parabolic. The same is probably true, though to a less marked degree, of the regressions involving the breadth of the egg. It is thus clear that the actual regression surface, in the case of multiple regression, is not a plane but rather a curved surface, either convex or concave, as the case may be. If an equation could be determined which would take account of this curvature of the regression surface, the prediction, especially near the bounding edges of the surface, should be much more satisfactory. The general theory of multiple nonlinear regression has not been developed mathematically. Hence it was necessary in dealing with the matter to start *de novo*.

It was decided first to test a paraboloid surface, generated by moving one parabola in such a way that its vertex was always on another parabola whose axis was parallel to the axis of the first, the vertical planes of the two parabolas being at right angles to each other.

The general equation for such a paraboloid surface is

$$Z=a+\frac{x}{b}+\frac{y}{c}+\frac{x^2}{d}+\frac{y^2}{e}$$

where $a, b, \ldots e$ are constants to be determined from the data. The signs of the constants determine whether the surface is concave or convex.

On account of the considerable amount of calculation involved in the determination of the constants of such an equation, it was decided to try first of all an abbreviated form by dropping out the x and y terms, thus:

$$Z=a+\frac{x^2}{b}+\frac{y^2}{c}$$

It was found, however, that this equation did not give a satisfactory graduation, and the complete form was subsequently calculated.

Also on account of the labor involved in the calculations only one regression surface has been fitted. This is for the regression of weight on length and breadth. This regression is by far the most important one for practical purposes. If a reasonably close graduation of the data could be determined, such an equation would permit one to ascertain the approximate weight of blown eggs (e. g., museum specimens) and also the approximate fresh weight of eggs which had been stored for various lengths of time.

The data used for this determination, as for the other regression equations, were those of series A. Since the observations were somewhat scattered near the ends of the range, it was necessary to group the data in somewhat larger classes than those used for the other equations. As may be seen from a study of Tables 20 and 21, the length unit chosen was 1½ millimeters. With the indicated units, distributions of the weights of the eggs falling in each length-breadth compartment were then made. The mean weight of the eggs falling in each compartment was taken as the observed weight for eggs of the indicated length and breadth. These observed weights are given in the tables in heavy-faced type, while the theoretical weights determined from the equations are given in light-faced type.

It may be observed here that the regression surface could be represented by erecting perpendicular ordinates from the center of each compartment, with the height of each ordinate proportional to the weight of the eggs in the class. A surface connecting the tops of these ordinates is the observed regression surface showing the relation of egg weight to length and breadth.

As stated above, the first attempt to graduate this paraboloid surface was made with the abbreviated general equation:

$$Z=a+\frac{x^2}{b}+\frac{y^2}{c}$$

For convenience $\frac{1}{b}$ and $\frac{1}{c}$ may be represented by q and r, and the equation becomes

$$Z=a+qx^2+ry^2$$

where z = weight, x = length, and y = breadth. The constants of this equation were evaluated by the method of least squares.

The equation arrived at by this means was as follows:

$$Wt.=0.00833\ (Lt.)^2+0.01987\ (Br.)^2-6.1270$$

From this equation the theoretical weights of eggs having the mean length and breadth of each class in Table 20 were calculated. These results are shown in the table in light-faced type.

TABLE 20.—*Showing the observed (bold-faced figures) and calculated (light-faced figures) mean egg weights associated with particular length and breadth dimensions.*

Egg length, in millimeters.	Egg breadth, in millimeters.											
	38.00–38.74	38.75–39.49	39.50–40.24	40.25–40.99	41.00–41.74	41.75–42.49	42.50–43.24	43.25–43.99	44.00–44.74	44.75–45.49	45.50–46.24	46.25–46.99
49.0–50.4	43.75	44.91	48.09	**43.66** 47.29	48.51	49.75	51.02	52.31	53.62	54.95	56.31	57.69
50.5–51.9	**42.98** 45.02	46.17	47.37	**47.71** 48.55	49.77	**53.14** 51.01	**53.62** 52.28	**54.26** 53.57	54.88	56.21	57.58	58.96
52.0–53.4	46.32	**47.94** 47.47	**46.84** 48.65	**48.61** 49.85	**50.44** 51.07	**52.29** 52.31	**53.55** 53.58	**56.92** 54.87	56.18	57.51	58.87	60.25
53.5–54.9	**45.65** 47.65	**46.01** 48.81	**49.01** 49.98	**49.76** 51.18	**52.25** 52.41	**53.80** 53.65	**55.43** 54.92	**57.52** 56.71	**57.39** 57.52	58.85	60.21	61.59
55.0–56.4	**47.13** 49.03	**48.98** 50.18	**49.56** 51.36	**51.44** 52.56	**53.25** 53.78	**55.32** 55.02	**57.19** 56.29	**59.48** 57.58	**61.04** 58.89	**62.67** 60.23	61.58	62.96
56.5–57.9	50.44	**49.73** 51.59	**50.49** 52.77	**52.79** 53.97	**54.67** 55.19	**56.36** 56.44	**58.56** 57.70	**60.42** 58.99	**61.45** 60.30	**65.72** 61.64	62.99	**68.48** 64.37
58.0–59.4	51.89	**50.08** 53.04	**52.61** 54.22	**54.90** 55.42	**55.50** 56.64	**58.43** 57.89	**61.03** 59.15	**62.15** 60.44	**65.80** 61.75	**68.03** 63.09	**67.54** 64.44	65.82
59.5–60.9	53.38	**50.45** 54.53	**52.64** 55.71	**55.71** 56.91	**57.90** 58.13	**59.41** 59.37	**62.20** 60.64	61.93	**65.07** 63.24	**67.82** 64.57	65.93	67.31
61.0–62.4	54.90	**56.06** 56.06	57.23	**57.06** 58.43	**60.52** 59.65	60.90	62.17	**67.53** 63.45	64.77	66.10	67.46	68.83
62.5–63.9	56.46	57.62	**54.59** 58.79	**57.36** 59.99	61.22	62.46	**64.62** 63.73	**69.47** 65.02	66.83	67.66	69.02	70.40
64.0–65.4	58.06	**55.94** 59.22	60.39	61.59	62.82	64.06	65.33	66.62	67.93	69.26	70.62	71.99
65.5–66.9	59.70	60.85	62.03	63.23	64.45	65.70	66.96	68.25	69.56	70.90	72.25	73.63
67.0–68.4	61.37	62.53	63.71	64.91	66.13	**66.54** 67.37	68.64	69.93	71.24	72.57	73.93	75.31

From this table we note the following points:

1. If the observed and calculated weights for classes falling near the center of the table are compared, they clearly agree very closely. In a few cases the difference reaches as much as 1 gram, but these differences balance each other. The general effect, then, is to smooth out the irregularities of the observations, and for the center of the table the graduation must be regarded as excellent.

2. However, a good fit for the center of the table was obtained from the multiple linear equations. It is at the ends and sides of the table that the real test comes. We may compare first the columns of the table. In the first column on the left side there are three observations. In each of these cases the observed weight is less than the calculated by approximately 2 grams. In the second column on this side there are eight observations, and here, with the exception of two cases, the observed weights are markedly less than the calculated. The same is true to a somewhat less degree of the third column.

3. Passing to the right side of the table, it will be seen that here the observed weights are significantly larger than the calculated. Thus, in the third column from the right there are four observations in which the observed weight exceeds the calculated by from 2.4 grams to nearly 5 grams.

4. At the top and bottom of the table it is also seen that there is considerable discrepancy between the observed and calculated weights.

5. There is, then, a marked tendency for the calculated weights to overestimate the observed weight in the case of narrow eggs and to underestimate it in the case of broad eggs. There is also a slight tendency to underestimate the weights of both very long and very short eggs. The observations at the top and bottom of the table, however, are too few and based on too small a number of eggs to make this point entirely certain.

The constants to this equation were calculated twice independently, and there do not appear to be any significant arithmetical errors to explain the discrepancies.

In view of the unsatisfactory graduation obtained with this equation it was decided to employ more constants. Accordingly, the complete general equation for this type of surface was used, viz:

$$Z = a + \frac{x}{b} + \frac{y}{c} + \frac{x^2}{d} + \frac{y^2}{e}$$

This was also evaluated by the method of least squares. The solution of this equation involved a considerable amount of arithmetical work.

The final equation, stated in terms of the egg characters, was:

$$Wt. = 0.0198 Lt. - 0.0426 Br. + 0.0172 (Lt.)^2 + 0.0322 (Br.)^2 - 56.6665.$$

The results obtained with this equation, while better than in any of the previous cases, were still not entirely satisfactory. Since considerable time had already been spent in calculating these equations, it was decided to try to modify the present formula empirically rather than to make a new assumption and calculate another equation. This method of procedure has a precedent in much of the curve fitting that is regularly done, e. g., in the usual way of dealing with certain logarithmic curves.

The method followed was to take the equation given above as a basis and then to modify its constants by small amounts so as to produce the desired effect, which was tested by interpolation. After a number of attempts, the following equation was reached:

$$Wt. = 1.0513 Lt. - 0.0426 Br. - 0.00059 (Lt.)^2 + 0.0322 (Br.)^2 - 56.6665.$$

The theoretical weights for the various classes were calculated from this equation, with the results shown in Table 21.

TABLE 21.—*Showing the observed (bold-faced figures) and calculated (light-faced figures) mean egg weights associated with particular length and breadth dimensions.*

Length, in millimeters.	Breadth, in millimeters.											
	38.00–38.74	38.75–39.49	39.50–40.24	40.25–40.99	41.00–41.74	41.75–42.49	42.50–43.24	43.25–43.99	44.00–44.74	44.75–45.49	45.50–46.24	46.25–46.99
49.0–50.4	39.88	41.72	43.59	**43.66** 45.50	47.45	49.43	51.35	53.50	55.59	57.72	59.88	62.08
50.5–51.9	**42.98** 41.37	43.21	45.08	**47.71** 46.99	48.93	**53.14** 50.92	**53.62** 52.93	**54.28** 54.99	57.08	59.20	61.37	63.57
52.0–53.4	42.85	**47.94** 44.69	**46.84** 46.57	**48.61** 48.47	**50.44** 50.42	**52.29** 52.40	**53.55** 54.42	**56.92** 56.47	58.56	60.69	62.85	65.05
53.5–54.9	**45.65** 44.34	**46.01** 46.17	**49.01** 48.05	**49.76** 49.96	**52.25** 51.90	**53.80** 53.88	**55.43** 55.90	**57.52** 57.95	**57.39** 60.04	62.17	64.33	66.53
55.0–56.4	**47.13** 45.82	**46.98** 47.65	**49.56** 49.53	**51.44** 51.47	**53.25** 53.38	**55.32** 55.36	**57.19** 57.38	**59.48** 59.44	**61.04** 61.52	**62.67** 63.65	65.81	68.01
56.5–57.9	47.29	**49.73** 49.13	**50.49** 51.00	**52.79** 52.91	**54.67** 54.83	**56.36** 56.84	**58.56** 58.86	**60.42** 60.91	**61.45** 63.00	**65.72** 65.13	67.29	**68.48** 69.49
58.0–59.4	48.76	**50.06** 50.60	**52.61** 52.48	**54.90** 54.38	**55.50** 56.33	**58.43** 58.31	**61.03** 60.33	**62.15** 62.38	**65.80** 64.47	**68.03** 66.60	**67.54** 68.76	70.96
59.5–60.9	50.24	**50.45** 52.07	**52.64** 53.95	**55.71** 55.85	**57.90** 57.80	**59.41** 59.78	**62.20** 61.80	63.85	**65.07** 65.94	**67.82** 68.07	70.23	72.43
61.0–62.4	51.84	**56.08** 53.68	55.56	**57.66** 57.46	**60.52** 59.41	61.39	63.41	**67.53** 65.46	67.55	69.68	71.84	74.04
62.5–63.9	53.17	55.01	**54.59** 56.88	**57.36** 58.79	60.73	62.72	**64.62** 64.73	**69.47** 66.79	68.88	71.00	73.17	75.37
64.0–65.4	54.63	**55.94** 56.47	58.34	60.25	62.20	64.18	66.20	68.25	70.34	72.47	74.63	76.83
65.5–66.9	56.09	57.93	59.80	61.71	63.66	65.64	67.66	69.71	71.80	73.93	76.09	78.29
67.0–68.4	57.55	59.40	61.26	63.17	65.11	**66.54** 67.10	69.11	71.17	73.26	75.38	77.55	79.75

A study of the observed and calculated weights in this table shows that the graduation is much better than in the other cases.

While there are still some discrepancies, it will be seen that these are evenly distributed over the table. The plus and minus deviations practically offset each other. As a matter of fact the sum of the deviations in which the calculated weight exceeds the observed gives a total of 28.086 grams, while for cases in which the observed weight exceeds the calculated the sum is 27.368 grams. Thus the total deviation in both directions for the 70 observed classes is 55.454 grams, giving a mean deviation of 0.792 gram.

It is further seen that in relatively few instances do the calculated and observed weights differ by more than about 1 gram. Greater deviations are nearly always in classes where only a single egg has furnished the "observed" record. Thus the largest single deviation for any class is found in the second column and the third row. Here the observed weight exceeds the calculated by 3.249 grams. This observation is based upon the weight of a single egg. Comparing its observed weight with those which are near it in the other classes, it is clear that it is larger than it should be.

In five other cases the differences between the observed and calculated weights reach 2 grams. In four of these cases the observed data are from single eggs, while in the other case the observation is based on two eggs, in one of which the observed weight is considerably too high, as shown by other eggs in near-by columns.

Since the preceding discussion of regression has been rather extended, it seems desirable to collect together here in one place the various regression formulæ. This will then be followed by a discussion of tests of some of these various formulæ on random samples of eggs.

Table of regression equations.

(1) $Wt.=1.1229\ Lt.-7.9792$. (See p. 207.)
(2) $Wt.=2.8035\ Br.-62.2483$. (See p. 208.)
(3) $Wt.=1.0704\ Blk.-0.2681$. (See p. 209.)
(4) $Blk.=1.0203\ Lt.-5.5879$. (See p. 207.)
(5) $Blk.=2.6431\ Br.-58.9081$. (See p. 208.)
(6) $Blk.=0.8979\ Wt.+2.2563$. (See p. 209.)
(7) $Wt.=0.9944\ Lt.+2.6595\ Br.-112.2168$. (See p. 216.)
(8) $Wt.=0.0459\ Lt.+1.0555\ Blk.-2.0809$. (See p. 216.)
(9) $Wt.=1.0978\ Blk.-0.0980\ Br.+2.4157$. (See p. 216.)
(10) $Blk.=0.0182\ Lt.+0.8925\ Wt.+1.5335$. (See p. 216.)
(11) $Blk.=0.4163\ Br.+0.7942\ Wt.-9.4630$. (See p. 216.)

WEIGHT ON LENGTH.

(12) $y_{xp}=1.2601x_p-0.093x_p^2+0.5299$. (See p. 211.)

BULK ON LENGTH.

(13) $y_{xp}=1.1607x_p-0.0952x_p^2+0.5420$. (See p. 211.)

WEIGHT ON LENGTH—PARABOLAS (METHOD OF MOMENTS).

(14) $y=56.1367\left\{1+0.1328\left(\frac{x}{l}\right)\right\}$. (See p. 212.)

(15) $y=56.1367\left\{1.0218+0.1328\left(\frac{x}{l}\right)-0.0654\left(\frac{x}{l}\right)^2\right\}$. (See p. 212.)

(16) $y=56.1367\left\{1.0218+0.0724\left(\frac{x}{l}\right)-0.0654\left(\frac{x}{l}\right)^2+0.1007\left(\frac{x}{l}\right)^3\right\}$. (See p. 212.)

(17) $y=56.1367\left\{1.0256+0.0724\left(\frac{x}{l}\right)-0.1037\left(\frac{x}{l}\right)^2+0.1007\left(\frac{x}{l}\right)^3+0.0447\left(\frac{x}{l}\right)^4\right\}$. (See p. 212.)

(18) $y=56.1367\left\{1.0256+0.1274\left(\frac{x}{l}\right)-0.1037\left(\frac{x}{l}\right)^2-0.1562\left(\frac{x}{l}\right)^3+0.0447\left(\frac{x}{l}\right)^4+0.2312\left(\frac{x}{l}\right)^5\right\}$. (See p. 212.)

(19) $y=56.1367\left\{1.0870+0.1274\left(\frac{x}{l}\right)-1.3925\left(\frac{x}{l}\right)^2-0.1562\left(\frac{x}{l}\right)^3+3.9112\left(\frac{x}{l}\right)^4+0.2312\left(\frac{x}{l}\right)^5-2.8354\left(\frac{x}{l}\right)^6\right\}$. (See p. 212.)

BULK ON LENGTH—PARABOLAS (METHOD OF MOMENTS).

(20) $y=52.5044\left\{1+0.1288\left(\frac{x}{l}\right)\right\}$. (See p. 212.)

(21) $y=52.5044\left\{1.0203+0.1288\left(\frac{x}{l}\right)-0.0610\left(\frac{x}{l}\right)^2\right\}$. (See p. 212.)

(22) $y=52.5044\left\{1.0203+0.0718\left(\frac{x}{l}\right)-0.0610\left(\frac{x}{l}\right)^2+0.0926\left(\frac{x}{l}\right)^3\right\}$. (See p. 212.)

(23) $y=52.5044\left\{1.0287+0.0718\left(\frac{x}{l}\right)-0.1450\left(\frac{x}{l}\right)^2+0.0926\left(\frac{x}{l}\right)^3+0.0980\left(\frac{x}{l}\right)^4\right\}$. (See p. 212.)

(24) $y=52.5044\left\{1.0287+0.1169\left(\frac{x}{l}\right)-0.1450\left(\frac{x}{l}\right)^2-0.1114\left(\frac{x}{l}\right)^3+0.0980\left(\frac{x}{l}\right)^4+0.1836\left(\frac{x}{l}\right)^5\right\}$. (See p. 213.)

(25) $y=52.5044\left\{1.0904+0.1169\left(\frac{x}{l}\right)+1.2305\left(\frac{x}{l}\right)^2-0.1114\left(\frac{x}{l}\right)^3+13.5352\left(\frac{x}{l}\right)^4+0.1836\left(\frac{x}{l}\right)^5+11.7305\left(\frac{x}{l}\right)^6\right\}$. (See p. 213.)

WEIGHT ON BREADTH—PARABOLAS (METHOD OF LEAST SQUARES).

(26) $Wt.=2.793\ Br.-61.345$. (See p. 214.)

(27) $Wt.=0.111\ (Br.)^2-6.620\ Br.+136.855$. (See p. 214.)

BULK ON BREADTH.

(28) $Blk.=2.692\ Br.-60.558$. (See p. 214.)

(29) $Blk.=0.043\ (Br.)^2-2.347\ Br.+31.598$. (See p. 214.)

WEIGHT ON LENGTH AND BREADTH.

(30) $Wt.=0.0083\ (Lt.)^2+0.0199\ (Br.)^2-6.1270$. (See p. 218.)

(31) $Wt.=0.0198\ Lt.-0.0426\ Br.+0.0172\ (Lt.)^2+0.0322\ (Br.)^2-56.6665$.

(32) $Wt.=1.0513\ Lt.-0.0426\ Br.-0.00059\ (Lt.)^2+0.0322\ (Br.)^2-56.6665$.

TESTS OF REGRESSION EQUATIONS.

A test of certain of the regression equations was made on a random sample of 20 eggs from Series A. Starting with egg No. 1, every fifteenth egg which had been used in the original data was selected until 20 were obtained. The theoretical weight of each of these 20 eggs was calculated by selected equations and the difference between this and the actual weight of the egg was found in each case. The mean deviation regardless of sign was taken as the measure of accuracy of the estimation.

Only the equations for estimating the weight have been used in this test, and in the case of the parabolas only those which have been shown to give the best fits.

In Table 22 the actual weight of the eggs used is given in the second column. In each succeeding column there is given the difference between the observed and calculated weights. Appropriate signs indicate the direction of the deviation in each case. Thus when the calculated weight is larger than the observed, the sign is + and when smaller the sign is −. The numbers at the tops of the columns refer to the equation numbers as given on pages 222–223. The total and mean deviations are given at the bottoms of the columns. The column of the observed weights shows whether the egg was exceptionally heavy or light as compared with the mean weight of eggs of this series as given in Table 2.

Table 22.—*Showing the results given by different regression equations on a random sample of eggs.*

Egg No.	Observed weight.	Difference between observed weight and the weight calculated by equation No. —												
		1	2	3	7	8	9	12	14	15	26	27	30	32
	Gms.	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*
1	56.88	− 0.50	−0.96	+1.72	+1.77	+1.81	+1.78	+ 1.71	+ 0.96	+ 0.74	−0.50	−1.15	+1.39	+1.83
2	52.96	− 1.19	+2.68	− .51	− .49	− .62	− .60	− 1.98	− 1.25	− .40	+3.09	+2.44	− .40	− .37
3	57.13	+ .76	−4.29	− .34	−1.84	− .25	−2.63	+ 1.10	+ .36	+ .30	−3.82	−4.31	−1.11	−1.74
4	51.07	+ 3.09	+ .22	− .46	− .55	− .44	− .44	+ 3.40	+ 3.22	+ 4.17	+ .70	+ .39	+ .90	− .37
5	53.15	+ 2.19	+1.98	+1.14	+1.18	+1.12	+1.12	+ 1.55	+ 1.32	+ 2.24	+2.45	+1.81	+1.21	+1.25
6	56.74	− 1.40	− .26	−1.20	−1.14	−1.24	−1.24	− 2.04	− 2.27	− 1.35	+ .20	− .45	−1.57	−1.03
7	59.88	− 2.31	−2.08	− .17	− .16	− .14	− .15	− 1.89	− 2.41	− 2.46	−1.63	−2.24	−1.20	− .08
8	69.47	− 6.64	−7.64	− .50	−1.27	− .39	− .39	− 9.41	− 9.32	−10.31	−7.20	−7.40	−3.55	−1.11
9	61.70	− 3.23	−4.29	−1.55	−1.56	−1.49	−1.51	− 3.06	− 3.80	− 4.05	−3.84	−4.47	−2.46	−1.45
10	65.80	− 7.74	−3.49	− .99	−1.37	−1.01	− .99	− 7.44	− 8.19	− 8.30	−3.05	−3.17	−3.90	−1.12
11	69.51	−11.05	−4.96	−1.81	−2.51	−1.85	−1.82	−10.95	−11.55	−11.83	−4.53	−4.19	−5.74	−2.12
12	59.83	− .19	−5.42	−1.74	−1.55	− .60	−1.64	− .49	− 1.24	− 1.82	−4.96	−5.56	−1.44	−1.54
13	50.11	+ 4.15	+ .90	− .56	− .74	− .57	− .56	+ 2.99	+ 3.14	+ 4.15	+1.38	+1.11	+ .89	− .54
14	52.81	− .79	+2.88	+ .96	− .01	− .14	− .12	− 1.43	− .81	− 2.09	+3.35	+2.70	+ .01	+ .11
15	52.31	+ 3.85	− .18	+ .72	+ .78	+ .78	+ .77	+ 4.43	4.79	+ 4.32	+ .30	− .12	+1.82	+ .92
16	49.63	+ 2.80	+2.00	− .15	− .32	− .18	− .17	+ 2.57	4.70	+ 3.80	+2.48	+2.12	+1.14	− .14
17	54.84	+ 1.71	−1.05	+ .05	+ .17	+ .11	+ .09	+ 2.28	+ 2.37	+ 2.00	− .58	−1.15	+ .58	+ .26
18	54.96	− .31	+ .94	+ .24	+ .31	+ .21	+ .21	+ 1.92	− .19	+ .69	+1.40	−1.91	+ .08	+ .41
19	54.08	− .29	+1.05	− .28	− .24	− .32	− .32	− .11	− .16	+ .83	+1.52	+ .88	− .17	− .14
20	43.66	+ 4.25	+7.58	+1.85	+1.27	+1.69	+1.74	− .15	+ 2.97	+ 1.00	+8.06	+7.75	+3.40	+1.45
Totals	......	58.44	54.85	16.94	19.23	14.96	18.29	60.90	65.02	66.85	55.04	55.32	32.96	18.08
Means	......	2.92	2.74	.85	.96	.75	.91	3.05	3.25	3.34	2.75	2.77	1.65	.90

From this table it is seen that five of the equations tested give an average error of less than 1 gram in the prediction of the weight of these 20 eggs. This means an error of about 2 per cent. It would appear that this is probably about as close as it is possible to approximate to the weight of an egg by means of regression equations based on linear dimensions.

Comparing the different equations it is seen that the best result on the 20 eggs taken for the test is given by equation No. 8, which is the multiple linear regression equation for weight on length and bulk. The computed bulk, of course, involves the breadth of the egg. It has been shown earlier in this bulletin that the bulk calculated by the formula here used gives a close approximation to the true volume. So virtually equation 8 is for the regression of weight on the length and volume of the egg.

It is of interest to note that in spite of the fact of nonlinearity of the weight regressions in general, nevertheless a linear equation when tested on a random sample of eggs gives as good a result as the best of the nonlinear equations.

If the weight of the egg is to be estimated on the basis of but a single linear dimension, breadth is apparently slightly the better dimension to choose, and equation 2 the best equation. Here again we see the regression line giving a better result than either the best fitting straight line to the unweighted means or the second order parabola fitted by least squares, even though the latter fits the observed regression line better than the regression equation 2.

The underlying purpose with which this investigation of regression was undertaken was to test concretely whether the true theory of regression which takes account of the variabilities of the related characters would give distinctly better results than the simple graduation, by least squares or moments, of the observed, unweighted regression means. On theoretical grounds there could be no doubt as to the outcome. It is a source of some satisfaction, however, to have a concrete and practical demonstration that even though we may fit with a theoretical curve or surface the observed regression points or surfaces much closer than they are fitted by the true regression equations, nevertheless, when the resulting prediction formulæ are tested on random samples from the same population, no substantial gain in accuracy of prediction is obtained. On the contrary, in not a few cases the results will be distinctly worse than with a true regression equation, even though the latter involves fewer characters.

VARIATION AND CORRELATION IN THE EGGS OF WILD BIRDS AS COMPARED WITH THE DOMESTIC FOWL.

Under conditions of domestication it is obvious that there can be no natural selection of the fowl on the basis of physical characters of the egg. Furthermore, in the stock which furnished the data of Series A there has been no artificial selection in respect to size, shape, or color of eggs, at least for a considerable period of years. It is evident, then, that whatever degree of variation is exhibited in this stock in respect to these characters is independent of any influence of selection. On the other hand, it has been generally assumed by followers of the neo-Darwinian school of evolutionary philosophy that the eggs of wild birds have been and are the objects of natural selective processes, and that their characteristics in respect of size, shape, and color are in some degree determined by natural selection. This conclusion has been definitely stated by Latter[1] for the cuckoo's egg.

In view of these considerations it is of interest to compare the eggs of the domestic fowl with those of wild birds in respect of variation and correlation. Considerable material is available for such comparison.

First may be considered variation and correlation in the egg of *Corvus frugilegus* L. The data here analyzed for this form are those published some years ago by Tur.[2] In his discussion of the data Tur considered only simple variation and calculated no correlations. The data include 200 eggs. One hundred and eighty-eight of these were collected from 73 nests. The remainder were "extra" eggs, for which the history was not known. In forming the correlation tables from these data we made use of units of grouping somewhat different from those used by Tur in his calculations of the frequency constants. This accounts for the slight discrepancies between his values and those here tabled.

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[1] Latter, O. H. The Egg of Cuculus canorus. An Enquiry into the Dimensions of the Cuckoo's Egg and the Relation of the Variation to the Size of the Eggs of the Foster Parent, with Notes on Coloration, etc. *Biometrika*, Vol. I, pp. 164–176, 1902.

[2] Tur, Jan. Wahania indywidualne jaj gawrona (*Corvus frugilegus* L.), zebranych w Wilanowie pod Warszawa w kwietniu r. 1906. Pamietnika Fizjograficznego, T. XIX, pp. (of reprint) 1–15, 1906.

In Table 23 are given the variation constants for the eggs of the rook.

TABLE 23.—*Constants for variation in the egg of Corvus frugilegus L.* (*Tur's data.*)

Character.	Mean.	Standard deviation.	Coefficient of variation.	Coefficient of variation for corresponding characters of fowls' eggs (from Table 2).	Difference between rook and fowl coefficients.
Length ....mm..	40.025±0.103	2.156±0.073	5.387±0.182	4.237±0.095	+1.150±0.205
Breadth..................do....	28.183± .040	.843± .028	2.992± .101	3.287± .074	− .295± .125
Weight....................gm..	16.335± .071	1.497± .050	9.166± .312	8.364± .189	+ .802± .365

The coefficients of correlation for these characters of the rook's egg are as follows:

Correlation of length and breadth, $r = 0.257 \pm 0.045$.

Correlation of length and weight, $r = 0.672 \pm 0.026$.

Correlation of breadth and weight, $r = 0.844 \pm 0.013$.

Of these constants only the coefficients of variation and correlation are directly comparable between the fowl and the rook. By reference to Table 2 it will be seen that:

1. The relative variation and the degree of correlation are of the same general order of magnitude in the case of the egg of the fowl and that of the rook. There is no evidence whatsoever of that considerable increase in variability in the fowl's egg, which on *a priori* grounds might be supposed to result from the cessation of selection, both natural and artificial. with reference to the characters under discussion.

2. The egg of the rook is *more* variable in length than that of the fowl, to a degree which is statistically significant. In the case of weight the rook's egg is also more variable than the fowl's. The difference, however, is only a little more than twice the probable error and can not safely be regarded as statistically significant.

3. The egg of the rook is somewhat less variable in breadth than the fowl's egg, but the difference is probably not significant.

In considering these differences in variation it must be remembered that the rook's eggs are in clutches, and do not represent the product of 200 different individuals. On this account they might be expected to be somewhat less variable than the hens' eggs. In spite of this factor and in spite of any putative influence of natural selection, the eggs of the rook exhibit *greater* relative variability than hens' eggs in respect to two out of three characters measured.

A similar comparison of a wild bird's eggs with those of the domestic fowl may be made for the English sparrow (*Passer domesticus*). Pearson[1] has published the variation constants for tolerably long series of the eggs of this bird, including both his own and Bumpus' series of measurements on English birds, and the American series of Bumpus. This comparison is made in Table 24. Another character the breadth/length index, may be compared in this case. For this character the standard deviations are directly comparable.

TABLE 24.—*Showing the relative variability of eggs of* (*a*) *Passer domesticus and* (*b*) *the domestic fowl.*

Character.	English series (Pearson).	English series (Bumpus).	American series (Bumpus).	Fowl.
Length (coefficient of variation)	5.47	4.91	4.92	4.24
Breadth (coefficient of variation)	3.38	(?)	(?)	3.29
Index (standard deviation)	3.76	3.22	3.68	3.79

From this table it is evident that the sparrow's and the hen's egg are substantially equally variable in dimensional characters. In respect to length and breadth the egg of the sparrow is somewhat more variable than that of the fowl, not less variable, as it would be expected to be if natural selection were an important factor in determining the degree of variation exhibited by birds' eggs. None of the differences in Table 24 can be regarded as statistically significant. In other words, the egg of the wild bird is neither more nor less variable than that of the domesticated fowl in this case.

Table 25 gives the coefficients of variation for egg length and egg breadth in a number of different species of wild birds, as determined by Latter,[2] for comparison with the fowl.

TABLE 25.—*Showing the relative variability of eggs of* (*a*) *various species of wild birds, and* (*b*) *the domestic fowl.*

Species.	Coefficient of variation for egg length.	Coefficient of variation for egg breadth.	Species.	Coefficient of variation for egg length.	Coefficient of variation for egg breadth.
Cuckoo	4.72	3.93	House sparrow	5.47	3.38
Blackbird	4.61	3.62	Hedge sparrow	4.02	2.81
Song thrush	3.64	2.50	Robin	4.24	3.09
Starling	3.68	1.94	Linnet	3.49	2.69
Wagtail[3]	6.96	2.52			
Yellowhammer	3.17	2.53	Mean (unweighted)	4.48	2.98
Tree pipit	3.49	2.97	Domestic fowl	4.29	3.79
Meadow pipit	6.37	3.84			

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[1] Pearson, K. Variation of the Egg of the Sparrow (*Passer domesticus*). Biometrika, Vol. I, pp. 256–257, 1902.

[2] Latter, O. H. Loc. cit., p. 176.

[3] A mixed series.

From this table we see that again the wild birds' eggs are more variable on the average in length than are those of the domestic fowl. The difference here is probably not significant. It indicates merely that the domestic fowl is certainly not, as might have been supposed to be the case on *a priori* grounds, more variable than wild birds in respect to egg length.

In breadth the eggs of the fowl show a higher coefficient than the average for the wild birds. In view of the other facts set forth in this section, however, probably but little significance can be attached to this result. It may be related to the greater laying activity of the domesticated bird, as a result of which the muscular tonus of the wall of the oviduct is not so precisely maintained at a given point as in the case of wild species laying but a few eggs. This suggestion is purely hypothetical, however. It is not yet clear by any means that the eggs of wild birds are in general actually less variable in breadth than those of the domestic fowl.

Considering all the facts set forth in this section together, they seem to us to make it highly probable that the essential factors concerned in the determination of the degree of variation in size and shape exhibited by birds' eggs are purely physiological and in no direct or immediate way (if at all) related to the action of natural selection. The physiological mechanism concerned in the determination of the shape and size of a bird's eggs involves chiefly the secretory and muscular systems of the oviduct. This mechanism is essentially similar in wild and domestic birds. It seems reasonable to suppose that it would lead to the same sort of result in respect to variation of product in the one case as in the other.

It certainly does not appear from the available evidence that it is essential to the survival of a wild bird that its eggs shall be less variable than those of the domestic fowl, in which egg variation obviously had no survival value whatsoever.

VARIATION IN THE SIZE OF EGGS IN THE INDIVIDUAL AS COMPARED WITH THE RACE.

So far we have considered only intraracial variation in the size of eggs. Clearly egg production offers an excellent opportunity to carry the analysis of variation further, through the discussion of intraindividual variation. The same bird produces a considerable number of eggs in the course of a year. How much variation is shown by the eggs of the same individual bird as compared with that exhibited by the flock or race as a whole? Poultrymen are generally impressed with the similarity of the eggs of the same bird, which is indeed striking in some cases. On the other hand, as will presently appear, there are other individuals whose eggs vary among themselves quite as much or even more than do the eggs of the flock or the race. Individuality of a bird in respect to nonuniformity (i. e., variability) of its product is just as definite and real a phenomenon as is the more commonly known individuality in respect to average size, shape, or color of the product.

It should be said before entering upon the discussion of the data that intraindividual variation in eggs has been made the subject of a very thorough investigation by Dr. Maynie R. Curtis, working in this laboratory. Her researches have extended over a period of years. The results will be published shortly. The discussion of the data in the present bulletin is only preliminary to the more thorough treatment which she will give the matter.

The material for the present treatment of intraindividual variation in eggs (Series B, p. 176) was derived from 100 Barred Plymouth Rock hens, all approximately 1 year old at the time the data were taken. These birds were a part of the same stock which furnished the data for Series A. The intraindividual and the racial data are therefore strictly comparable in the present case. Twenty-five consecutive eggs were measured from each of the 100 birds, double-yolked or otherwise abnormal eggs being rejected. The eggs were taken during the spring laying cycle (cf. Part II of this study, p. 99); that is, in the months of March, April, and May. Dr. Curtis has shown in her unpublished work that the eggs of this season of the year constitute an almost absolutely perfect random sample of the total eggs produced during the year. This, of course, demonstrates the validity of the present data for the use to which they are put, namely, the study of intraindividual variation. The length and breadth of each of the 2,500 eggs used in this study were measured to hundredths of a millimeter. Then for each of the 100 birds the mean, standard deviation, and coefficient of variation for length and breadth were calculated from the sample of 25 eggs. In making these calculations the data were not grouped.

In Table 26 the constants for each bird are given.

TABLE 26.—*Constants for intraindividual variation in length and breadth of the eggs of 100 Barred Plymouth Rock hens.*

Case No.	Bird No.	Length.			Breadth.		
		Mean.	Standard deviation.	Coefficient of variation.	Mean.	Standard deviation.	Coefficient of variation.
1	1	53.08	1.28	2.40	42.64	0.81	1.89
2	7	56.14	1.62	2.88	41.09	.51	1.25
3	8	55.54	1.38	2.49	42.27	.72	1.69
4	10	54.45	1.76	3.24	40.61	1.16	2.86
5	12	55.38	1.39	2.51	42.11	.91	2.16
6	18	57.23	2.17	3.79	41.07	1.00	2.44
7	19	56.09	2.31	4.13	40.04	1.18	2.94
8	20	55.77	1.38	2.48	42.73	1.06	2.47
9	21	55.31	1.84	3.33	41.08	.61	2.46
10	23	52.10	1.12	2.14	38.36	.75	1.95
11	27	59.78	1.87	3.13	42.06	1.12	2.66
12	39	57.82	1.50	2.59	42.90	1.01	2.35
13	42	54.71	1.23	2.25	42.71	.48	1.12
14	52	54.78	1.73	3.15	41.49	1.21	2.92
15	58	58.50	1.86	3.18	42.63	.77	1.81
16	61	57.73	2.45	4.24	41.39	.76	1.84
17	66	57.89	2.04	3.53	42.65	.69	1.63
18	73	53.97	1.07	1.98	44.64	.90	2.01
19	87	55.19	1.29	2.34	41.61	.47	1.14
20	90	58.28	1.66	2.85	42.57	.66	1.54
21	99	56.27	2.09	3.71	41.65	.79	1.91
22	112	59.09	1.63	2.76	40.36	.64	1.58
23	113	55.04	1.24	2.26	42.69	.61	1.42
24	121	54.78	1.72	3.15	40.34	.75	1.86
25	122	54.16	1.45	2.67	41.09	.73	1.77
26	129	54.04	1.51	2.79	41.94	.98	2.34
27	152	55.55	1.26	2.27	42.22	.74	1.74
28	160	58.80	1.94	3.29	42.03	.75	1.78
29	C161	59.63	1.58	2.64	41.60	.42	1.00
30	168	56.10	1.15	2.05	41.29	.70	1.71
31	172	54.35	1.96	3.61	42.29	.98	2.31
32	185	57.17	.94	1.64	43.41	.61	1.41
33	224	56.23	1.62	2.87	40.91	.71	1.74
34	233	55.00	1.35	2.45	41.77	1.19	2.85
35	243	55.90	1.60	2.87	43.14	.61	1.42
36	352	55.60	1.27	2.29	40.73	.72	1.78
37	357	54.14	2.14	3.95	42.39	1.33	3.13
38	359	56.24	1.93	3.43	43.71	.51	1.17
39	367	53.70	1.33	2.48	39.34	.84	2.14
40	374	58.85	1.82	3.09	44.22	.95	2.15
41	375	56.81	1.45	2.55	43.29	.57	1.31
42	377	55.63	2.00	3.59	41.08	.76	1.84
43	381	55.97	1.47	2.63	41.68	.88	2.11
44	382	53.42	1.42	2.67	41.03	.95	2.32
45	389	56.34	1.98	3.51	41.38	1.08	2.50
46	393	55.55	2.04	3.67	40.17	1.19	2.95
47	395	55.22	1.75	3.16	42.01	.97	2.32
48	397	57.06	1.35	2.36	43.48	.37	.86
49	400	55.65	2.00	3.59	39.82	.44	1.11
50	401	54.05	2.18	4.03	43.24	.96	2.23
51	402	56.40	1.94	3.44	40.61	.62	1.53
52	406	57.43	2.25	3.92	40.87	1.27	3.10
53	408	57.80	1.06	1.83	42.94	0.50	1.17
54	409	59.40	1.73	2.92	45.33	.66	1.45
55	410	55.04	1.48	2.70	41.25	1.00	2.42
56	414	58.68	1.48	2.52	43.28	1.09	2.52
57	415	56.36	1.83	3.25	41.66	.89	2.15
58	419	64.89	1.54	2.80	41.57	.60	1.44
59	422	56.86	1.57	2.76	41.78	.59	1.41
60	424	54.72	1.36	2.48	43.15	1.28	2.98
61	428	53.73	1.44	2.68	42.57	.71	1.66
62	434	56.33	1.40	2.48	42.50	.47	1.10
63	438	56.20	1.40	2.49	42.24	.83	1.96
64	441	58.49	1.98	3.39	44.96	.93	2.08
65	442	54.92	1.18	2.14	41.44	.62	1.51
66	443	54.33	1.07	1.96	41.23	.60	1.45
67	444	55.09	1.03	1.87	42.27	.74	1.76
68	447	51.08	1.42	2.63	41.90	.91	2.17
69	450	55.60	1.61	2.89	42.90	.87	2.04
70	C559	56.82	1.69	2.98	40.82	.65	1.59
71	705	56.28	1.65	2.94	41.80	1.25	2.99
72	707	54.72	1.47	2.68	38.87	.92	2.37
73	709	55.94	2.68	4.79	40.79	.78	1.92
74	712	53.32	1.41	2.65	40.69	.82	2.01
75	717	57.10	1.82	3.19	41.70	.67	1.60
76	725	56.36	1.86	3.30	40.49	.98	2.42
77	726	58.67	2.42	4.13	41.87	.90	2.16
78	731	56.42	1.56	2.76	38.99	1.32	3.39
79	732	57.34	1.42	2.48	41.50	.70	1.68
80	734	57.40	2.00	3.49	39.62	1.08	2.72
81	743	59.03	2.84	4.81	42.32	.89	2.11
82	744	56.53	1.61	2.84	42.90	.83	1.94
83	745	57.71	2.07	3.59	41.54	1.09	2.62
84	749	58.10	1.22	2.10	42.08	.40	.94
85	752	52.57	1.31	2.49	39.95	.67	1.68
86	757	55.52	1.52	2.74	44.46	.51	1.14
87	759	58.04	1.27	2.19	44.13	.51	1.15
88	762	55.01	1.11	2.02	42.67	.64	1.51
89	763	58.22	1.54	2.65	42.18	.42	1.01
90	764	55.38	1.52	2.75	42.86	.58	1.36
91	765	55.10	1.53	2.78	40.96	.62	1.52
92	766	52.41	1.45	2.76	41.91	.82	1.95
93	768	55.54	1.68	3.02	39.54	.81	2.06
94	770	55.01	1.55	2.82	41.36	.72	1.73
95	771	57.28	2.24	3.91	42.99	.68	1.59
96	774	52.95	1.40	2.64	41.70	1.71	4.11
97	777	55.37	1.90	3.43	41.38	.94	3.77
98	784	55.65	.87	1.56	39.18	.65	1.65
99	803	57.52	1.82	3.17	42.41	1.13	2.66
100	1780	53.90	.84	1.56	42.77	.64	1.49
General means		56.09	1.62	2.89	41.83	.81	1.97

From this table we note that:

1. There is a great diversity among these 100 birds in respect not only to the mean size of the eggs produced but also in respect to the uniformity of the product. Some of the birds, as, for example, Nos. 185, 444, 784, and 1780, lay eggs which are all very closely alike in size (i. e., show little variation). On the other hand, other birds lay eggs which are extremely variable. Examples of this are Nos. 61 (in length), 19, 709 (in length), 774 (in breadth). The relative variability of the egg is plainly a definite character of the individual.

2. There is, *on the average*, a considerable reduction in variability as we pass from the race to the individual. The mean length and mean breadth deduced from the individual means agree almost exactly, as they would be expected to, with the racial means from Series A. For the variabilities the case is different. Since the means are substantially identical, we may compare standard deviations directly. We then have for length—

Racial S. D. (2.39) – Mean individual S. D. (1.62) = 0.77

and for breadth—

Racial S. D. (1.38) – Mean individual S. D. (0.81) = 0.57

3. Put in another way, the mean individual standard deviation in length is 68 per cent of the racial standard deviation, or there is a reduction in variability in length of 32 per cent in passing from race to individual. The mean individual standard deviation in breadth is 59 per cent of the racial standard deviation. In this character the reduction in variability is 41 per cent. It is of interest to note that the reduction is greater for breadth than for length. Dr. Curtis also finds this to be the case in her work.

4. There are 4 hens whose eggs show a greater standard deviation in length than does a random sample of eggs of the race. That is, the eggs of these birds are absolutely more variable in length than the eggs of the flock of Barred Rock birds from which they originated. Among the 100 individuals none laid eggs more variable (absolutely) than those of the race in respect to breadth.

5. Looking at the matter from the standpoint of relative variability in proportion to mean size, as measured by the coefficient of variation, we find two birds (Nos. 709 and 743) whose eggs are relatively more variable than those of the race in respect to length. Three birds (Nos. 731, 774, and 777) lay eggs which are relatively more variable in breadth than those of the race.

6. While in the race, and on the average for individuals, the egg is more variable in length than in breadth, there are individual birds in whose eggs this rule is reversed. Out of the 100 birds, two (Nos. 20 and 414) lay an egg which is equally variable in length and breadth. Seven birds out of the 100 produce eggs which are more variable in breadth than in length.

In 22 cases of repeated like parts in the vegetable kingdom, including various characters of leaves of trees, etc., Pearson[1] found an average reduction of variability in passing from race to individual of about 13 per cent. This is obviously very much smaller than what we find for eggs. The results indicate that the eggs of an individual hen are, on the average, from three to four times more uniform in size than are the leaves from an individual tree. This difference is interesting because of the physiological differences of egg formation and leaf formation (for example). In the one case the product, as measured, is essentially the result of secretory activity, whereas in the other case the product is a result of cell division and differentiation.

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[1] Pearson, K., and others. Mathematical Contributions to the Theory of Evolution.—IX. On the Principle of Homotyposis and its Relation to Heredity, to the Variability of the Individual, and to that of the Race. Phil. Trans. Roy. Soc., Vol. 197A, pp. 285–379, 1901.

The data of Table 26 offer material for the study of a number of problems in regard to the formation of the egg. We hope later to return to the discussion of some of these. At present only one further matter will be considered, namely, the interindividual correlations. Is there a correlation in respect to absolute and relative variability between length and breadth of the egg? In other words, does the hen which lays an egg with a high absolute variability (standard deviation) in length also tend to show a high absolute variability in breadth? Is relative variability (coefficient of variation) in length correlated with relative variability in breadth?

To answer these questions correlation tables have been prepared from the data of Table 26. Table 27 shows the interindividual correlation in respect to mean length and mean breadth. Table 28 gives the correlation between the standard deviation for length and that for breadth, or, in other words, the interindividual correlation in respect to absolute variability between length and breadth. Table 29 gives the interindividual correlation in respect to relative variability; that is, the correlation between the coefficients of variation for length and breadth.

TABLE 27.—*Showing the correlation between individual mean egg length and individual mean egg breadth.*

		Egg breadth means.																
		37.5–37.9	38.0–38.4	38.5–38.9	39.0–39.4	39.5–39.9	40.0–40.4	40.5–40.9	41.0–41.4	41.5–41.9	42.0–42.4	42.5–42.9	43.0–43.4	43.5–43.9	44.0–44.4	44.5–44.9	45.0–45.4	Total.
Egg length means.	52.0–52.4	.....	1	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	2
	52.5–52.9	.....	.....	.....	.....	1	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	2
	53.0–53.4	.....	.....	.....	.....	.....	.....	1	1	.....	.....	1	.....	.....	.....	.....	.....	3
	53.5–53.9	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	2	.....	.....	.....	1	.....	4
	54.0–54.4	.....	.....	.....	.....	.....	.....	1	2	2	2	.....	1	.....	.....	.....	.....	8
	54.5–54.9	.....	.....	1	.....	.....	1	.....	2	1	.....	1	1	.....	.....	.....	.....	7
	55.0–55.4	.....	.....	.....	.....	.....	.....	1	4	2	3	3	.....	.....	.....	.....	.....	13
	55.5–55.9	.....	.....	.....	1	2	1	2	1	1	3	1	1	.....	1	.....	.....	14
	56.0–56.4	.....	.....	1	.....	.....	2	2	3	3	1	1	.....	1	.....	.....	.....	14
	56.5–56.9	.....	.....	.....	.....	.....	.....	1	.....	1	.....	1	1	.....	.....	.....	.....	4
	57.0–57.4	.....	.....	.....	.....	1	.....	1	1	2	.....	1	2	.....	.....	.....	.....	8
	57.5–57.9	.....	.....	.....	.....	.....	.....	.....	1	1	1	3	.....	.....	.....	.....	.....	6
	58.0–58.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	2	1	.....	.....	1	1	.....	5
	58.5–58.9	.....	.....	.....	.....	.....	.....	.....	.....	1	1	1	1	.....	1	.....	.....	5
	59.0–59.4	.....	.....	.....	.....	.....	1	.....	.....	.....	1	.....	.....	.....	.....	.....	1	3
	59.5–59.9	.....	.....	.....	.....	.....	.....	.....	.....	1	1	.....	.....	.....	.....	.....	.....	2
Total....		0	1	2	2	4	5	9	15	17	15	16	7	1	3	2	1	100

TABLE 28.—*Showing the correlation between individual standard deviations for egg length and egg breadth.*

Egg length standard deviations.	Egg breadth standard deviations. 0.30–0.49	0.50–0.69	0.70–0.89	0.90–1.09	1.10–1.29	1.30–1.49	1.50–1.69	1.70–1.89	Total.
0.70–0.89		2							2
.90–1.09		3	2						5
1.10–1.29	3	4	5						12
1.30–1.49	2	3	8	7	2			1	23
1.50–1.69	2	9	6	2	1	1			21
1.70–1.89		3	3	3	4				13
1.90–2.09	1	3	3	6	1				14
2.10–2.29		1		2	1	1			5
2.30–2.49			1	1	1				3
2.50–2.69			1						1
2.70–2.89			1						1
Total....	8	28	30	21	10	2	0	1	100

TABLE 29.—*Showing the correlation between individual egg length coefficients of variation and individual egg breadth coefficients of variation.*

Egg length coefficients of variation.	Egg breadth coefficients of variation. 0.70–0.89	0.90–1.09	1.10–1.29	1.30–1.49	1.50–1.69	1.70–1.89	1.90–2.09	2.10–2.29	2.30–2.49	2.50–2.69	2.70–2.89	2.90–3.09	3.10–3.29	3.30–3.49	3.50–3.69	3.70–3.89	3.90–4.09	4.10–4.29	Total.
1.50–1.69				2	1														3
1.70–1.89			1			1													2
1.90–2.09				1	1	1	1												4
2.10–2.29		1	2	1	1	2	1												8
2.30–2.49	1	2	1		3	1	1	1			1	1							12
2.50–2.69		2		1	1	1	1	3	4	1								1	15
2.70–2.89			2	4	3	2	3		1					1					16
2.90–3.09				1	1		1	1				1							5
3.10–3.29			1		1	3		1	2	1	1	1							11
3.30–3.49			1		1		1		1		1					1			6
3.50–3.69			1		1	1			2	1		1							7
3.70–3.89							1		1										2
3.90–4.09					1			1				1	1						4
4.10–4.29						1		1				1							3
4.30–4.49																			0
4.50–4.69																			0
4.70–4.89							2												2
Total...	1	5	9	10	15	13	12	8	11	3	3	6	1	1	0	1	0	1	100

The constants deduced from these tables are given in Table 30. The slight differences in the means in this table from those at the foot of Table 26 are due simply to the grouping of the data.

TABLE 30.—*Constants of interindividual variation and correlation in length and breadth of eggs.*

Intraindividual constant.	Mean.	Standard deviation.
Mean length	[1] 56.02±.1.14	1.68±.08
Mean breadth	41.82±.09	1.30±.06
Standard deviation for length	1.62±.03	.38±.02
Standard deviation for breadth	.82±.02	.25±.01
Coefficient of variation for length	2.88±.04	.66±.03
Coefficient of variation for breadth	1.95±.04	.64±.03

Correlation between length and breadth, intraindividual means .... $r=+.300\pm.061$
Correlation between intraindividual standard deviations for length and breadth .... $r=+.301\pm.061$
Correlation between intraindividual coefficients of variation for length and breadth...... $r=+.327\pm.060$

All probable errors in this table are calculated on the basis of $n=100$.

From this table it will be noted that:

1. The length constants are in all cases more variable than the breadth constants. This means biologically (*a*) that if we determine the mean length and breadth of a series of eggs from each of a number of birds we shall find more variation among the mean lengths than among the mean breadths, just as in the eggs of one bird or of a flock we usually find a greater variation in length of egg than in breadth; (*b*) that if in each of our series of eggs we calculate the standard deviation and coefficient of variation for the length and for the breadth of the eggs of each individual bird, we shall find that the series of standard deviations and coefficients of variation vary more among themselves in the case of length of egg than in the case of breadth of egg. In other words, not only is the hen's egg generally more variable in length than in breadth, but in passing from individual to individual there is a greater variation in respect to degree of variability—or uniformity, as one pleases—in length than in breadth.
2. The interindividual correlation in mean length and mean breadth is higher than the general intraracial coefficient for the same two characters (Table 14). This is to be expected. It means that in general a hen which characteristically lays an egg longer than the average also lays an egg which tends to be wider than the average; that is, a relatively large egg altogether.
3. The same sort of correlation holds in regard to the variability of the product. A hen which characteristically lays an egg which is unusually variable in length also exhibits an unusual degree of variation in the breadth of her product.

The results of this section carry an important practical suggestion. Those having to do with the development and organization of the marketing side of the poultry industry are all the time laying more and more stress on the importance of quality to the producer. The farmer and poultryman is urged to grade his eggs carefully before marketing them. So far as size and shape go, eggs are graded before anything else for uniformity. It is commonly assumed that lack of uniformity in eggs is primarily the result of having many different birds in the flock each of which lays an egg more or less different from every other bird's eggs. The results set forth above show that this is not the whole story. A study of Table 26 will very quickly convince one that there is a considerable portion of the flock composed of individuals which are constitutionally incapable of laying a uniform egg. Variability of product is as definite a characteristic of such hens as their color. On the other hand, there are hens whose eggs are remarkably and characteristically uniform. It is plain that these facts offer a hopeful suggestion to the breeder who is desirous of producing the highest quality of market eggs at the lowest cost. His aim will be to breed a pure strain of birds characterized not only by the average excellence but also by the uniformity of their product. It should finally be said that while the facts set forth above deal only with size characters of eggs, unpublished results obtained in this laboratory show that the same considerations apply to other characters of eggs.

SUMMARY.

The object of the present part of this bulletin is to present quantitative data, together with a biometrical analysis of the same, regarding the normal variation and correlation of the egg of the domestic fowl in respect primarily to size and shape. Such data are of value in connection with all physiological and genetic studies in regard to the production of eggs. They also have a significant relation to the economic problem of the improvement of eggs in respect to quality and uniformity by breeding. The material used in this study comprised a considerable number of eggs of Barred Plymouth Rock pullets belonging to the Maine Station flock. The material was strictly homogeneous, and particularly well adapted in all respects for the study of the normal variation of the hen's egg. It will be understood that the results and conclusions of this investigation, while stated in general form, are not presumed to have a wider generality than the material on which they are based. It is probable that many of the results found for the egg of the Barred Plymouth Rock will also obtain for the eggs of other breeds.

Among the more important results obtained in this study the following may be mentioned:

1. The egg is, to a significant degree, relatively more variable in length than in breadth. The egg is considerably more variable in shape, as measured by the length-breadth index, than it is in either of the linear dimensions length or breadth. The weight of the egg and its volume (determined from length and breadth on the assumption that the egg is a perfect prolate spheroid) are much more variable than any of the other characters. (Pp. 117–180.)

2. There is a close agreement between the egg of the domestic fowl and the human skull in respect to the degree of variation exhibited in the corresponding size and shape characters of the two structures. A consideration of the processes concerned in the production of the definitive size and shape of the egg and the skull suggests, though it does not prove, that this similarity with reference to variation constants is not fortuitous, but rests upon a basis of general similarity in regard to mechanical factors operative in both cases during the development and fixation of the final form. (Pp. 180–183.)

3. With the exception of breadth, all other dimensional characters studied show significantly skew (asymmetrical) variation. The different egg dimensions give frequency distributions following different

ones of Pearson's curve types. Variation of the egg in length and in shape (length-breadth index) follows a curve of Type IV; variation in breadth Type II, and variation in volume Type I. (Pp. 183–189.)

4. All of the egg dimensions studied are positively correlated with each other in varying degree. Intraracially egg length and egg breadth are correlated only slightly. Furthermore, neither the weight nor the volume of the egg is more than very slightly, if significantly at all, correlated with its shape. As would be expected, both length and breadth are significantly correlated with the weight and the volume of the egg. The bulk measures (volume and weight) are more highly correlated with breadth than with length. There is a very high correlation between volume and weight. This implies what was found in fact to be the case, that the specific gravity of the egg exhibits only a very small degree of variation. There is no significant net correlation between the shape of an egg and its absolute size. (Pp. 190–200.)

5. The skull and the egg show a correspondence in respect to the degree to which their chief dimensions are correlated. The correlation results parallel those already set forth in paragraph 2 above for simple variation. (Pp. 200–203.)

6. A detailed study of the regression of the weight of the egg on length and breadth results in certain equations from which the former quantity can be estimated from a knowledge of the linear dimensions of the egg with a considerable degree of accuracy. (Pp. 203–225.)

7. A comparison of the egg of the domestic fowl with those of a number of species of wild birds in respect to relative variability leads to the result that in general the eggs of wild birds are neither less nor more variable than those of the domestic bird. It is concluded that probably the essential factors concerned in the determination of the degree of variation in size and shape exhibited by birds' eggs are purely physiological and in no direct or immediate way (if at all) related to the action of natural selection. It does not appear from the evidence that it is essential to the survival of a wild bird that its egg shall be less variable than those of the domestic fowl, in which egg variation obviously has no survival value whatsoever. (Pp. 225–228.)

8. A study of intraindividual variation indicates that the relative variability of eggs is a definite characteristic of the individual, some birds characteristically laying eggs which are extremely variable and other birds characteristically producing eggs which are very uniform. There is on the average a considerable reduction in variability in passing from the race to the individual. This amounts in the case of length to 32 per cent and in the case of breadth to 41 per cent. Some individuals may show a greater variability both

absolute and relative than a random sample of the eggs of the race from which the individual comes. The rule that length is more variable than breadth is reversed in the eggs of some individuals. Seven per cent of the birds studied produce eggs which are more variable in breadth than in length. In general a hen which characteristically lays an egg longer than the average also lays an egg which tends to be wider than the average. The same sort of correlation holds in regard to the variability of the product. A hen which characteristically lays an egg which is unusually variable in length also exhibits an unusual degree of variation in the breadth of her product. (Pp. 228–234.)

APPENDIX III.

In Table I of this appendix are given the original measurements for the eggs of Series A used in this investigation. These measurements are published here in the hope that they may be useful to other students of the physiology of egg production, and in general as a set of basic records of the normal variation of the egg in a homogeneous flock of domestic fowls.

Table I.—*Giving the original measurements of the eggs comprising Series A of this bulletin (cf. p. 176).*

Egg No.	Length.	Breadth.	Weight.	Index.	Bulk.	Egg No.	Length.	Breadth.	Weight.	Index.	Bulk.
	mm.	*mm.*	*gms.*	*Per ct.*	*c. c.*		*mm.*	*mm.*	*gms.*	*Per ct.*	*c. c.*
1	59.10	42.15	56.88	71.32	55.00	54	58.39	41.18	54.35	70.53	51.84
2	56.64	42.64	57.35	75.28	53.92	55	50.96	40.74	47.18	79.95	44.29
3	53.40	41.46	51.24	77.27	48.06	56	57.19	42.17	56.60	73.74	53.22
4	57.06	42.25	56.51	74.05	53.35	57	53.57	38.94	45.39	72.69	42.52
5	56.94	42.77	58.61	75.12	54.56	58	55.08	41.91	54.16	76.09	50.68
6	53.54	41.29	51.52	77.11	47.81	59	54.58	40.54	50.12	74.28	46.97
7	56.46	43.18	58.57	76.48	55.11	60	58.07	40.76	54.19	70.19	50.52
8	54.55	40.16	49.81	73.27	46.07	61	55.95	42.97	58.51	76.80	54.13
9	57.51	40.65	54.07	70.67	49.79	62	51.51	42.81	53.62	83.12	49.41
10	55.64	41.19	52.02	74.03	49.40	63	55.50	41.87	53.15	75.44	50.97
11	55.25	42.28	54.92	76.52	51.72	64	52.32	40.93	48.91	78.23	45.87
12	53.07	42.08	52.19	79.29	49.21	65	54.14	42.96	54.63	79.35	52.32
13	56.38	39.06	51.26	69.28	45.04	66	54.60	43.82	58.71	80.26	54.89
14	55.75	42.76	56.65	76.70	53.38	67	54.36	42.40	55.58	78.00	51.17
15	51.26	38.66	42.98	75.42	40.11	68	59.79	40.71	55.20	68.09	51.90
16	57.71	42.10	56.33	72.95	53.57	69	51.08	43.43	53.88	85.02	50.47
18	53.21	42.03	52.96	79.99	49.25	70	55.68	45.18	62.72	81.14	59.51
19	57.27	40.35	53.40	70.46	48.85	71	56.46	43.97	62.80	77.88	57.13
20	54.74	40.55	51.60	74.08	47.15	72	54.82	41.60	53.00	75.88	49.61
21	57.76	42.49	59.60	73.56	54.63	73	55.98	43.00	57.24	76.81	54.20
22	58.27	41.61	56.87	71.41	52.81	74	54.90	43.25	58.25	78.78	53.79
23	56.94	41.90	55.42	73.59	52.34	75	58.75	42.37	59.24	72.12	55.26
24	52.82	39.74	45.42	75.24	43.68	76	55.02	39.94	50.28	72.60	49.96
25	56.80	39.92	49.73	70.28	47.39	77	52.20	42.49	53.14	81.40	49.37
26	57.73	40.54	54.82	70.22	49.69	78	55.50	42.35	56.74	76.31	52.14
27	57.07	41.81	55.72	73.26	52.22	79	59.44	41.13	55.56	69.20	52.69
28	57.75	41.31	55.56	71.53	51.64	80	54.44	40.27	49.29	73.97	46.25
29	56.73	40.44	51.74	71.29	48.59	81	54.24	41.62	52.49	76.93	49.19
30	56.54	40.87	52.84	72.29	49.47	82	53.85	42.32	54.89	78.59	50.51
31	55.71	41.23	51.97	74.01	49.62	83	58.59	41.12	54.79	70.18	51.86
32	57.02	44.01	61.41	77.18	57.80	84	52.88	41.64	51.93	78.74	48.01
33	58.66	41.05	57.13	71.00	53.31	85	53.10	42.05	51.15	79.19	49.18
34	51.46	43.36	54.63	84.26	50.66	86	56.70	42.83	59.25	75.54	54.48
35	57.80	41.93	56.79	72.54	53.23	87	54.56	40.15	49.34	73.59	46.07
36	62.13	38.76	52.06	62.39	48.88	88	56.56	41.90	55.09	94.08	51.99
37	58.36	41.44	55.53	71.02	52.48	89	57.25	39.63	48.61	69.22	47.11
38	57.60	44.25	62.89	76.82	59.08	90	57.45	42.06	56.71	73.21	53.22
39	57.79	44.10	61.12	76.31	58.84	91	57.63	41.73	55.77	72.41	52.58
40	57.33	42.93	59.42	77.88	55.36	92	54.67	41.52	53.35	75.95	49.36
41	67.92	41.88	66.54	61.66	62.37	93	58.37	42.82	59.88	73.36	56.03
42	54.80	40.46	51.25	73.84	46.97	94	61.05	43.87	67.53	71.86	61.56
43	56.89	42.63	56.89	74.93	51.15	95	56.73	43.17	61.01	76.10	55.39
44	59.47	42.03	58.44	70.67	55.74	96	54.41	38.14	45.65	70.10	41.43
45	58.28	43.00	60.60	73.78	56.42	97	55.48	40.02	50.26	72.13	46.53
46	60.17	40.95	57.50	68.06	52.85	98	54.37	41.11	52.43	75.61	48.14
47	57.98	41.74	55.69	71.99	52.89	99	61.10	40.60	55.87	64.45	52.73
48	55.34	40.50	51.07	73.18	47.53	100	58.56	43.17	62.29	73.72	57.17
49	57.83	42.99	59.41	74.34	55.95	101	55.77	43.76	61.38	78.47	55.93
50	57.12	41.57	55.74	72.78	51.66	102	56.39	40.77	54.09	72.30	49.09
51	54.42	41.28	52.08	75.85	48.56	103	63.50	42.58	64.92	65.59	60.28
52	55.00	44.50	61.22	80.90	57.03	104	57.74	41.03	54.70	71.06	50.92
53	58.60	43.56	61.69	74.33	58.22	105	56.31	43.53	59.72	77.30	55.85

TABLE I.—*Giving the original measurements of the eggs comprising Series A of this bulletin* (*cf. p. 176*)—Continued.

Egg No.	Length.	Breadth.	Weight.	Index.	Bulk.	Egg No.	Length.	Breadth.	Weight.	Index.	Bulk.
	mm.	*mm.*	*gms.*	*Per ct.*	*c. c.*		*mm.*	*mm.*	*gms.*	*Per ct.*	*c. c.*
106	56.66	40.45	53.10	71.39	48.57	183	54.45	40.40	50.11	74.20	46.54
107	63.33	40.53	57.36	64.00	54.50	184	56.41	42.46	56.51	75.27	53.24
108	63.06	44.26	69.47	70.19	64.68	185	60.61	41.87	60.26	69.08	55.65
109	54.48	42.01	54.71	77.11	50.36	186	54.86	41.56	52.82	75.76	49.61
110	56.56	41.90	55.35	74.08	51.99	187	62.49	41.51	60.52	66.43	56.39
111	57.03	42.67	58.29	74.82	54.40	188	56.07	41.36	53.83	73.76	50.23
112	57.52	40.30	53.43	70.06	48.91	189	58.44	42.35	60.24	72.47	54.90
113	57.33	42.47	58.74	74.08	54.18	190	53.27	42.51	54.06	79.80	50.44
114	56.58	41.88	56.62	74.02	51.96	191	56.46	43.59	60.15	77.20	56.14
115	56.53	41.06	53.30	72.63	49.91	192	56.59	40.96	52.89	72.38	49.70
116	56.34	39.74	50.53	70.53	46.59	193	55.88	42.16	56.45	75.35	52.00
117	58.89	42.17	59.44	71.60	54.85	194	55.62	40.34	52.27	72.53	47.39
118	56.19	41.88	56.51	74.53	51.59	195	56.30	40.31	50.64	71.59	47.87
119	54.99	41.92	54.72	76.23	50.59	196	57.29	42.09	55.72	73.47	53.12
120	55.19	41.97	55.14	76.05	50.92	197	54.97	42.66	56.06	77.61	52.39
121	55.65	44.02	59.76	79.10	56.42	198	53.43	42.07	52.81	78.74	49.55
122	55.11	42.09	56.00	76.37	51.10	199	53.36	42.49	54.26	79.63	50.42
123	59.18	42.68	61.70	72.12	56.44	200	56.35	40.47	51.47	71.82	48.36
124	59.35	43.81	64.65	73.82	59.63	201	57.71	40.12	50.40	69.52	48.65
125	53.03	42.41	53.00	79.98	49.93	202	52.62	42.56	53.63	80.88	49.91
126	57.07	40.93	53.89	71.71	50.04	203	58.41	43.88	62.62	75.12	58.88
127	54.65	40.43	49.60	73.98	46.80	204	54.95	40.28	49.35	73.30	46.69
128	57.65	43.98	63.31	76.28	58.34	205	54.63	42.83	56.11	78.40	52.51
129	59.14	41.01	56.03	69.34	52.10	206	56.55	42.29	56.88	74.74	52.94
130	53.79	41.74	54.00	77.60	49.06	207	56.52	41.57	54.12	73.55	51.16
131	54.03	43.03	56.00	79.64	52.42	208	57.00	42.24	56.83	74.00	53.25
132	55.32	40.37	49.72	72.98	47.18	209	61.06	40.53	56.09	66.38	52.24
133	57.35	41.85	56.52	72.98	52.61	210	55.38	40.60	51.80	73.31	47.80
134	57.31	42.57	57.44	74.28	54.41	211	57.84	41.62	56.26	71.96	52.46
135	53.03	40.37	48.68	76.13	45.28	212	53.10	42.12	52.99	79.32	49.33
136	55.50	41.58	54.14	74.92	50.24	213	57.12	40.80	52.31	71.43	49.79
137	55.45	44.48	62.37	80.22	57.45	214	53.42	41.38	51.55	77.46	47.89
138	58.81	44.43	65.80	75.54	60.80	215	57.18	41.92	56.39	73.31	52.61
139	57.33	46.34	68.48	80.84	64.47	216	56.82	42.70	58.18	75.15	54.24
140	54.46	39.79	48.65	69.40	45.12	217	56.70	43.35	59.29	76.45	55.82
141	57.63	42.03	57.87	72.93	53.34	218	56.21	40.82	52.34	72.62	49.03
142	55.63	41.24	53.34	74.13	49.55	219	56.32	41.86	55.04	74.32	51.67
143	56.84	45.07	65.72	79.29	60.48	220	58.08	42.90	60.14	73.86	55.97
144	59.73	40.03	52.63	67.02	50.15	221	55.55	40.03	50.43	72.06	46.64
145	61.04	40.79	56.81	66.82	53.15	222	52.70	40.79	48.22	77.40	45.89
146	55.65	41.57	53.97	74.70	50.34	223	55.65	41.94	55.25	75.36	51.26
147	57.07	42.51	57.78	74.49	54.03	224	54.86	43.53	58.01	79.35	54.45
148	51.30	40.92	47.37	79.77	45.98	225	52.38	42.12	51.66	80.42	48.66
149	54.66	43.29	58.28	79.20	53.66	226	58.12	42.78	61.63	73.61	55.69
150	57.72	41.95	57.25	72.68	53.21	227	54.77	41.93	52.61	76.56	50.43
151	56.47	40.02	50.95	70.87	47.36	228	53.80	40.62	49.63	75.50	46.48
152	55.86	41.47	54.24	74.24	50.32	229	55.88	42.40	55.14	75.88	52.60
153	59.26	45.23	69.51	76.32	63.50	230	56.33	44.54	61.87	79.07	58.52
154	60.29	40.39	56.36	66.72	51.46	231	52.93	42.04	51.96	79.43	48.99
155	55.33	41.52	53.86	75.04	49.95	232	56.25	42.46	57.09	75.48	53.10
156	56.66	40.87	53.40	72.13	49.68	233	56.88	41.09	53.29	72.24	50.26
157	56.49	44.26	61.56	78.35	57.93	234	54.54	41.48	51.99	76.05	49.14
158	57.57	43.25	61.73	75.13	56.42	235	58.86	45.52	66.99	77.34	63.85
159	54.56	40.98	50.08	75.11	47.98	236	58.66	43.19	60.63	73.63	57.27
160	59.29	42.60	61.15	71.85	56.33	237	54.08	41.85	53.31	77.39	49.62
161	53.36	40.98	49.94	76.80	46.92	238	52.50	42.26	51.14	80.49	49.09
162	57.16	42.37	58.01	74.13	53.25	239	55.16	43.70	58.48	79.22	55.16
163	56.20	43.13	59.84	76.74	54.76	240	55.00	39.93	48.20	72.60	45.94
164	64.91	39.03	55.94	60.13	51.81	241	52.55	41.37	49.06	75.28	47.12
165	55.55	41.81	54.97	75.27	50.83	242	53.39	40.19	48.37	78.73	45.12
166	60.18	41.80	58.69	69.49	54.00	243	57.47	41.39	54.84	72.02	51.53
167	58.00	39.12	50.19	67.45	46.47	244	54.06	43.04	56.07	79.61	52.43
168	60.13	41.61	59.83	69.20	54.52	245	57.04	40.63	53.24	71.23	49.83
169	60.98	44.99	68.52	73.78	64.59	246	56.40	38.38	47.13	68.05	43.50
170	54.40	41.82	53.87	76.88	49.81	247	56.58	40.85	52.44	72.20	49.46
171	58.40	43.17	61.29	73.92	57.01	248	59.75	42.93	62.20	71.85	57.69
172	60.29	39.64	52.10	65.75	49.61	249	52.20	40.96	49.32	78.47	45.85
173	57.52	41.71	55.71	72.51	52.42	250	62.07	40.75	59.47	65.65	54.00
174	54.47	41.92	53.24	76.96	50.13	251	56.37	39.90	49.52	70.78	46.98
175	56.72	42.75	56.97	75.37	54.30	252	56.40	42.98	57.88	76.20	54.50
176	54.95	40.70	50.05	74.67	47.67	253	57.56	41.75	56.25	72.53	52.56
177	52.46	43.40	55.16	82.73	51.74	254	57.62	43.53	60.58	75.55	57.19
178	58.18	42.40	58.77	72.88	54.76	255	51.30	42.47	52.19	82.79	48.47
179	55.15	42.86	56.77	77.72	53.06	256	53.32	39.42	47.94	63.93	43.38
180	59.70	44.39	65.07	74.36	61.56	257	56.21	42.00	55.66	74.72	51.91
181	60.11	38.77	50.45	64.50	47.29	258	55.72	42.12	54.90	75.59	51.76
182	55.85	39.76	48.95	71.19	46.24	259	58.09	40.54	53.94	69.79	49.08

Table I.—*Giving the original measurements of the eggs comprising Series A of this bulletin* (*cf. p. 176*)—Continued.

Egg No.	Length.	Breadth.	Weight.	Index.	Bulk.	Egg No.	Length.	Breadth.	Weight.	Index.	Bulk.
	mm.	*mm.*	*gms.*	*Per ct.*	*c. c.*		*mm.*	*mm.*	*gms.*	*Per ct.*	*c. c.*
260	56.03	42.02	54.59	75.00	51.81	339	55.77	43.07	56.49	77.23	54.20
261	56.39	40.74	51.38	72.25	48.99	340	59.61	42.39	59.59	71.11	56.07
262	53.99	43.00	55.97	79.64	52.26	341	54.58	41.34	51.07	75.74	48.84
263	56.46	41.23	53.59	73.02	50.23	342	55.85	42.01	54.66	75.22	51.64
264	55.95	44.14	60.07	78.89	57.09	343	54.75	42.35	55.19	77.35	51.45
265	56.75	43.19	60.04	76.10	55.41	344	54.23	40.69	49.03	75.03	46.99
266	57.79	42.85	59.45	74.53	55.58	345	55.36	40.52	51.99	73.19	47.59
267	54.54	42.29	54.23	77.54	51.04	346	54.53	41.84	54.34	76.73	49.99
268	53.02	42.76	52.94	80.65	50.76	347	54.58	40.73	49.58	74.62	47.43
269	56.68	40.46	50.59	71.38	48.58	348	60.64	44.76	66.95	73.81	63.61
270	55.04	42.24	54.58	76.74	51.42	349	57.51	39.30	49.73	68.34	46.52
271	55.86	42.97	57.96	76.93	54.03	350	54.03	42.15	52.98	78.01	50.29
272	54.48	41.70	52.87	76.54	49.60	351	54.74	43.04	56.56	78.63	53.09
273	56.68	41.32	53.14	72.90	50.67	352	54.93	40.69	51.44	74.08	47.60
274	55.01	41.87	54.08	76.11	50.51	353	55.98	39.46	46.70	70.49	45.64
275	54.84	40.77	48.39	74.34	47.75	354	59.73	42.40	60.55	70.99	56.23
276	53.74	43.17	55.25	80.33	52.41	355	52.55	43.14	53.45	82.09	51.22
277	57.01	42.51	56.95	74.56	53.96	356	52.72	43.45	54.57	82.42	52.14
278	58.14	39.39	49.98	67.75	47.21	357	55.32	43.05	56.28	77.82	53.71
279	55.91	41.88	54.06	74.91	51.35	358	56.41	41.21	53.47	73.05	50.17
280	53.69	44.43	57.39	82.75	55.46	359	57.39	40.69	52.94	70.90	49.72
281	55.09	43.66	58.41	79.25	54.97	360	53.93	39.35	46.06	72.96	43.75
282	56.41	42.42	56.23	75.20	53.14	361	55.63	42.54	55.29	76.47	52.72
283	57.38	42.86	59.52	74.70	54.23	362	56.21	42.41	55.99	75.45	52.95
284	57.60	40.18	52.14	69.76	48.69	363	55.73	42.02	54.61	75.40	51.53
285	53.98	40.40	48.86	74.84	46.13	364	54.87	42.46	53.72	77.38	51.80
286	56.39	42.55	57.03	75.47	53.47	365	57.13	40.48	51.73	70.68	49.02
287	56.78	44.60	62.33	78.55	59.14	366	56.54	41.77	52.64	73.88	51.67
288	58.12	45.81	68.09	78.82	63.83	367	59.48	43.18	62.04	72.60	58.06
289	49.77	40.48	43.66	71.33	42.71	368	55.93	41.24	53.64	74.06	49.81
290	57.68	43.77	59.69	75.88	57.83	369	52.64	40.13	46.42	76.23	44.36
291	58.26	41.10	53.13	70.54	51.53	370	63.47	42.84	64.43	67.50	61.00
292	53.32	41.95	51.49	78.67	49.15	371	55.40	42.97	57.28	77.56	53.16
293	53.95	41.35	50.29	76.64	48.33	372	53.96	41.25	51.08	76.44	48.09
294	52.86	41.21	50.41	77.96	46.98	373	59.40	42.14	57.48	70.94	55.23
295	56.96	40.27	51.67	70.70	48.39	374	55.27	42.27	54.93	76.48	51.74
296	53.43	43.55	61.07	81.51	53.09	375	56.71	43.34	58.90	76.42	55.68
297	53.31	40.83	50.08	76.59	46.56	376	59.67	42.22	59.20	70.75	55.70
298	53.83	42.89	52.18	79.68	51.88	377	58.42	43.61	61.38	74.65	58.14
299	54.66	39.82	47.72	72.85	45.38	378	54.98	41.90	53.51	76.21	50.29
300	54.89	40.66	48.81	74.07	47.52	379	57.65	41.85	55.61	72.59	52.90
301	57.19	41.49	55.93	72.55	49.06	380	53.27	40.91	47.31	76.80	46.71
302	59.16	42.26	58.26	71.43	55.32	381	56.67	44.05	60.72	77.73	57.61
303	55.98	42.50	56.85	75.92	52.94	382	52.99	40.11	47.13	75.69	44.65
304	54.24	40.83	49.61	75.28	47.37	383	59.65	40.13	53.20	67.27	50.33
305	52.96	41.76	51.70	78.85	48.36	384	52.60	40.70	47.74	77.38	45.62
307	63.89	42.68	64.52	66.80	60.93	385	54.00	40.26	48.43	74.55	45.83
308	63.00	39.68	54.59	62.98	51.94	386	57.58	42.42	56.47	73.67	54.25
309	58.74	45.24	66.56	77.01	62.95	387	55.60	42.42	54.79	76.29	52.39
310	58.23	43.44	60.65	74.60	57.54	388	57.08	41.72	53.04	73.09	52.02
311	58.02	39.94	51.71	68.84	48.46	389	56.95	40.05	51.27	70.32	47.86
312	55.54	40.22	48.99	72.42	47.14	390	57.06	41.67	55.14	73.03	51.90
313	58.48	43.38	60.88	74.18	57.62	391	52.63	43.81	56.86	83.24	52.51
314	57.69	43.86	62.23	76.03	58.09	392	57.02	39.88	50.78	69.94	47.48
315	56.02	40.85	52.25	72.92	48.92	393	57.73	41.24	53.59	71.43	51.42
316	57.69	41.84	55.71	72.53	52.87	394	57.11	42.98	59.29	75.26	55.25
317	57.38	40.43	52.29	70.46	49.13	395	55.97	45.38	62.62	81.08	60.36
318	56.69	43.45	59.39	76.64	56.05	396	56.61	43.94	60.49	77.62	57.23
319	55.19	42.33	54.19	76.70	51.79	397	56.87	43.18	58.72	75.93	55.53
320	55.68	44.74	61.94	80.35	58.36	398	54.50	40.09	48.47	73.56	45.84
321	55.00	41.03	50.51	74.48	48.59	399	56.60	42.78	56.65	75.58	54.24
322	54.88	42.28	54.22	77.04	51.37	400	59.16	43.32	64.54	73.22	58.13
323	55.85	42.01	55.40	75.22	51.64	401	57.25	42.79	59.72	74.74	54.87
324	57.85	43.60	61.31	75.37	57.59	402	54.44	43.27	56.76	79.48	53.40
325	53.69	41.23	49.04	76.80	47.80	403	52.05	40.54	47.67	77.89	44.80
326	57.68	42.12	56.84	73.02	53.58	404	54.93	42.00	52.41	76.46	50.74
327	59.09	41.94	57.12	70.98	54.41	405	57.85	44.19	62.89	76.39	59.13
328	58.62	41.50	55.06	70.80	52.86	406	59.03	40.13	53.52	67.98	49.81
329	57.53	43.42	60.26	75.47	56.78	407	56.24	40.45	50.17	71.92	48.20
330	53.30	42.60	53.65	79.92	50.65	408	54.77	43.66	57.89	79.71	54.67
331	54.56	42.00	52.74	76.08	50.39	409	56.92	41.79	54.69	73.42	52.02
332	54.94	43.19	55.45	78.61	53.64	410	55.36	41.48	52.54	74.93	49.87
333	57.24	41.76	56.65	72.96	52.27	412	54.41	42.46	54.25	78.04	51.35
334	57.35	42.37	56.08	73.88	53.80	413	57.89	42.13	57.94	72.77	53.82
335	55.80	41.98	55.17	75.23	51.40	414	56.76	42.12	55.04	74.21	52.73
336	53.97	39.51	46.29	73.21	44.13	415	52.22	41.43	48.56	79.34	46.95
337	54.51	42.04	53.73	77.12	50.45	416	60.19	42.32	58.92	70.31	56.43
338	59.73	42.11	58.67	70.50	55.49	417	55.20	42.95	57.63	77.81	53.34

TABLE I.—*Giving the original measurements of the eggs comprising Series A of this bulletin (cf. p. 176)*—Continued.

Egg No.	Length.	Breadth.	Weight.	Index.	Bulk.	Egg No.	Length.	Breadth.	Weight.	Index.	Bulk.
	mm.	*mm.*	*gms.*	*Per ct.*	*c. c.*		*mm.*	*mm.*	*gms.*	*Per ct.*	*c. c.*
418	56.65	43.49	58.54	76.77	56.09	436	57.57	41.82	54.78	72.64	52.73
419	54.58	41.60	54.74	76.22	49.46	437	57.70	40.73	53.60	70.59	50.14
420	54.11	42.21	53.61	78.00	50.46	438	57.44	41.41	53.61	72.09	51.59
421	56.48	43.37	57.46	76.79	55.65	439	54.45	41.60	52.16	76.40	49.44
422	57.27	40.63	51.53	70.94	49.60	440	54.47	39.74	46.27	72.96	45.05
423	59.51	41.71	57.15	70.09	54.24	441	56.48	39.96	49.06	70.75	47.22
424	57.37	43.78	61.51	76.31	57.56	442	54.24	43.53	56.23	80.25	53.84
425	59.13	42.79	60.02	72.36	56.67	443	54.17	41.89	52.37	77.33	49.74
426	57.15	42.91	58.83	75.08	55.13	444	56.22	39.77	49.03	70.74	46.59
427	56.79	44.03	60.50	77.53	57.66	445	58.11	43.32	60.77	74.55	57.11
428	55.27	44.03	58.28	79.66	56.13	446	54.04	43.29	57.08	80.11	53.00
429	55.98	43.53	57.71	77.76	55.57	447	51.46	40.35	48.51	78.41	43.89
430	59.52	40.83	53.80	68.60	51.98	448	55.60	40.15	47.92	72.21	46.95
431	59.05	43.41	62.17	73.51	58.30	449	58.12	41.15	55.90	70.80	51.56
432	53.82	43.74	56.50	81.27	53.91	450	54.11	40.76	48.25	75.33	47.08
433	55.58	42.51	54.73	76.48	52.62	451	56.82	43.29	58.71	76.19	55.73
434	54.80	39.06	46.58	71.28	43.78	452	59.56	41.02	56.73	68.87	52.47
435	59.79	44.87	67.99	75.04	63.05	453	58.85	40.81	55.67	69.35	51.30

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